MECHANICAL DRAWING

KENISON

AMERICAN SCHOOL of CORRESPONDENCE

CHICAGO ILLINOIS

LARGE BLACKBOARD USED IN THE DRAWING ROOM OF THE NEWTON MACHINE TOOL WORKS.

Mechanical Drawing

A Practical Manual of

SELF-INSTRUCTION IN THE ART OF DRAFTING, LETTERING, AND REPRODUCING PLANS AND WORKING DRAWINGS, WITH ABUNDANT EXERCISES AND PLATES

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Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

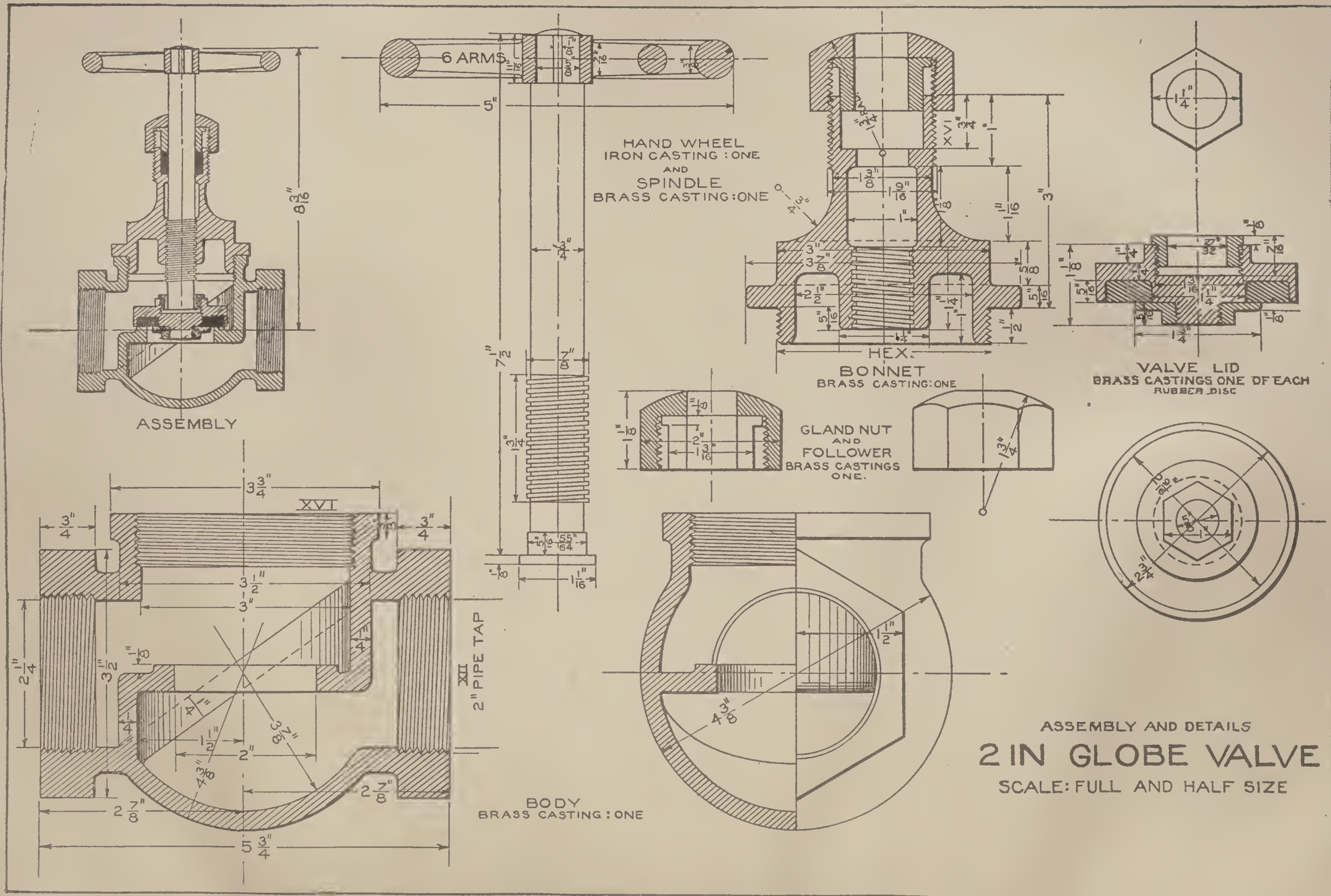
¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the com-

mon understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

Table of Contents



A TYPICAL WORKING DRAWING.

MECHANICAL DRAWING

PART I

The subject of mechanical drawing is of great interest and importance to all mechanics and engineers. Drawing is the method used to show graphically the small details of machinery; it is the language by which the designer speaks to the workman; it is the most graphical way to place ideas and calculations on record. Working drawings take the place of lengthy explanations, either written or verbal. A brief inspection of an accurate, well-executed drawing gives a better idea of a machine than a large amount of verbal description. The better and more clearly a drawing is made, the more intelligently the workman can comprehend the ideas of the designer. A thorough training in this important subject is necessary to the success of everyone engaged in mechanical work. The success of a draftsman depends to some extent upon the quality of his instruments and materials. Beginners frequently purchase a cheap grade of instruments. After they have become expert and have learned to take care of their instruments they discard them for those of better construction and finish. This plan has its advantages, but to do the best work, strong, well-made and finely finished instruments are necessary.

INSTRUMENTS AND MATERIALS.

Drawing Paper. In selecting drawing paper, the first thing to be considered is the kind of paper most suitable for the proposed work. For shop drawings, a manilla paper is frequently used, on account of its toughness and strength, because the drawing is likely to be subjected to considerable hard usage. If a finished drawing is to be made, the best white drawing paper should be obtained, so that the drawing will not fade or become discolored with age. A good drawing paper should be strong, have uniform thickness and surface, should stretch evenly, and should neither repel nor absorb liquids. It should also allow considerable erasing without spoiling the surface, and it should lie smooth when stretched or when ink or colors are used. It is, of

course, impossible to find all of these qualities in any one paper, as for instance great strength cannot be combined with fine surface.

In selecting a drawing paper the kind should be chosen which combines the greatest number of these qualities for the given work. Of the better class Whatman's are considered by far the best. This paper is made in three grades; the *hot pressed* has a smooth surface and is especially adapted for pencil and very fine line drawing, the *cold pressed* is rougher than the hot pressed, has a finely grained surface and is more suitable for water color drawing; the *rough* is used for tinting. The cold pressed does not take ink as well as the hot pressed, but erasures do not show as much on it, and it is better for general work. There is but little difference in the two sides of Whatman's paper, and either can be used. This paper comes in sheets of standard sizes as follows:—

Cap,	13 × 17 inches.	Elephant,	23 × 28 inches.
Demy,	15 × 20 "	Columbia,	23 × 34 "
Medium,	17 × 22 "	Atlas,	26 × 34 "
Royal,	19 × 24 "	Double Elephant,	27 × 40 "
Super-Royal,	19 × 27 "	Antiquarian,	31 × 53 "
Imperial,	22 × 30 "	Emperor,	48 × 68 "

The usual method of fastening paper to a drawing board is by means of thumb tacks or small one-ounce copper or iron tacks. In fastening the paper by this method first fasten the upper left hand corner and then the lower right pulling the paper taut. The other two corners are then fastened, and sufficient number of tacks are placed along the edges to make the paper lie smoothly. For very fine work the paper is usually stretched and glued to the board. To do this the edges of the paper are first turned up all the way round, the margin being at least one inch. The whole surface of the paper included between these turned up edges is then moistened by means of a sponge or soft cloth and paste or glue is spread on the turned up edges. After removing all the surplus water on the paper, the edges are pressed down on the board, commencing at one corner. During this process of laying down the edges, the paper should be stretched slightly by pulling the edges towards the edges of the drawing board. The drawing board is then placed horizontally and left to dry. After the paper has become dry it will be found to be as smooth and tight as a

drum head. If, in stretching, the paper is stretched too much it is likely to split in drying. A slight stretch is sufficient.

Drawing Board. The size of the drawing board depends upon the size of paper. Many draftsmen, however, have several boards of various sizes, as they are very convenient. The drawing board is usually made of soft pine, which should be well seasoned and straight grained. The grain should run lengthwise of the board, and at the two ends there should be pieces about $1\frac{3}{4}$ or 2 inches wide fastened to the board by nails or screws. These end pieces should be perfectly straight for accuracy in using the T-square. Frequently the end pieces are fastened by a glued

DRAWING BOARD

matched joint, nails and screws being also used. Two cleats on the bottom extending the whole width of the board, will reduce the tendency to warp, and make the board easier to move as they raise it from the table.

Thumb Tacks. Thumb tacks are used for fastening the paper to the drawing board. They are usually made of steel either pressed into shape, as in the cheaper grades, or made with a head of German silver with the point screwed and riveted to it. They are made in various sizes and are very convenient as they can be easily removed from the board. For most work however,

draftsmen use small one-ounce copper or iron tacks, as they can be forced flush with the drawing paper, thus offering no obstruction to the T-square. They also possess the advantage of cheapness.

Pencils. In pencilling a drawing the lines should be very fine and light. To obtain these light lines a hard lead pencil must be used. Lead pencils are graded according to their hardness, and are numbered by using the letter H. In general a lead pencil of 5H (or HHHHH) or 6H should be used. A softer pencil, 4H, is better for making letters, figures and points. A hard lead pencil should be sharpened as shown in Fig. 1. The wood is cut away so that about $\frac{1}{4}$ or $\frac{1}{2}$ inch of lead projects. The lead can then be sharpened to a chisel edge by rubbing it against a bit of sand paper or a fine file. It should be ground to a chisel edge and the corners slightly rounded. In making the straight lines the chisel edge should be used by placing it against the T-square or triangle, and because of the chisel edge the lead will remain sharp much longer than if sharpened to a point. This chisel edge enables the draftsman to draw a fine line exactly through a given point. If the drawing is not to be inked, but is made for tracing or for rough usage in the shop, a softer pencil, 3H or 4H, may be used, as the lines will then be somewhat thicker and heavier. The lead for compasses may also be sharpened to a point although some draftsmen prefer to use a chisel edge in the compasses as well as for the pencil.

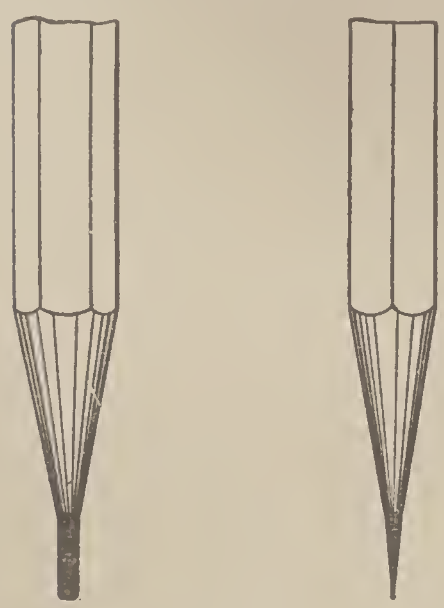


Fig. 1.

In using a very hard lead pencil, the chisel edge will make a deep depression in the paper if much pressure is put on the pencil. As this depression cannot be erased it is much better to press lightly on the pencil.

Erasers. In making drawings, but little erasing should be necessary. However, in case this is necessary, a soft rubber should be used. In erasing a line or letter, great care must be exercised or the surrounding work will also become erased. To prevent this, some draftsmen cut a slit about 3 inches long and $\frac{1}{8}$ to $\frac{1}{4}$ inch wide in a card as shown in Fig. 2. The card is then

placed over the work and the line erased without erasing the rest of the drawing. An erasing shield of a form similar to that shown in Fig. 3 is very convenient, especially in erasing letters. It is made of thin sheet metal and is clean and durable.

For cleaning drawings, a sponge rubber may be used. Bread crumbs are also used for this purpose. To clean the drawing

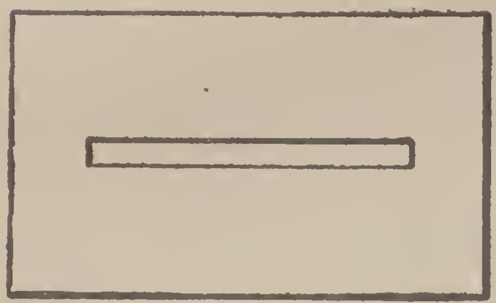


Fig. 2.

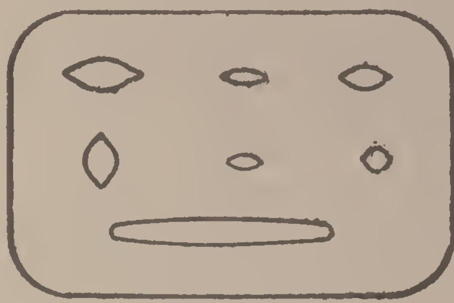


Fig. 3.

scatter *dry* bread crumbs over it and rub them on the surface with the hand.

T-Square. The T-square consists of a thin straight edge called the blade, fastened to a head at right angles to it. It gets

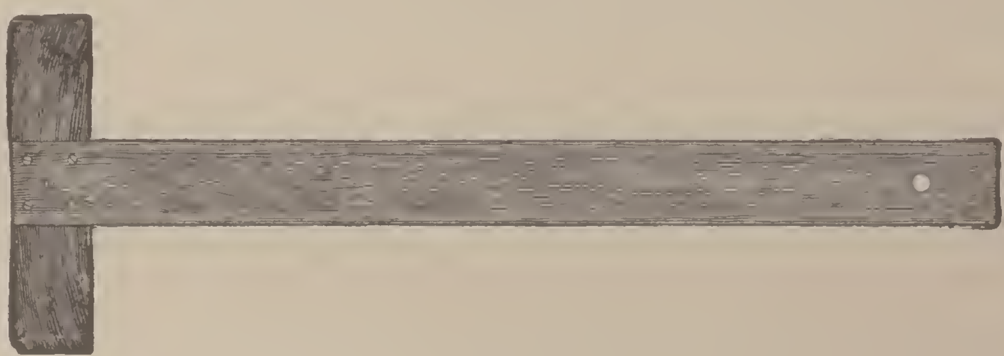


Fig. 4.

its name from the general shape. T-squares are made of various materials, wood being the most commonly used. Fig. 4 shows an ordinary form of T-square which is adapted to most work. In Fig. 5 is shown a T-square with edges made of ebony or mahogany, as these woods are much harder than pear wood or maple, which is generally used. The head is formed so as to fit against the left-hand edge of the drawing board, while the blade extends over the surface. It is desirable to have the blade of the T-square form a right angle with the head, so that the lines drawn with the T-square will be at right angles to the left-hand edge of the board. This, however, is not absolutely necessary, because the lines drawn with the T-square are always with reference to one edge of the

board only, and if this edge of the board is straight, the lines drawn with the T-square will be parallel to each other. The T-square should never be used except with the left-hand edge of the board, as it is almost impossible to find a drawing broad with the edges parallel or at right angles to each other.

The T-square with an adjustable head is frequently very convenient, as it is sometimes necessary to draw lines parallel to each

Fig. 5.

other which are not at right angles to the left-hand edge of the board. This form of T-square is similar to the ordinary T-square already described, but the head is swiveled so that it may be clamped at any desired angle. The ordinary T-square as shown in Figs. 4 and 5 is, however, adapted to almost any class of drawing.

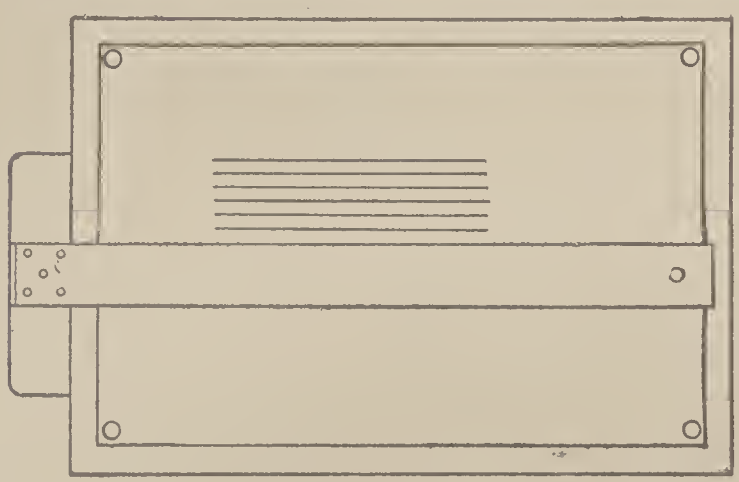


Fig. 6.

Fig. 6 shows the method of drawing parallel horizontal lines with the T-square. With the head of the T-square in contact with the left-hand edge of the board, the lines may be drawn by moving the T-square to the desired position. In using the T-square the upper edge should always be used for drawing as the two edges may not be exactly parallel and straight, and also it is more convenient to use this edge with the triangles. If it is necessary to use a straight edge for trimming drawings or cutting the paper from the board, the lower edge of the T-square should be used so that the upper edge may not be marred.

For accurate work it is absolutely necessary that the working edge of the T-square should be exactly straight. To test the

straightness of the edge of the T-square, two T-squares may be placed together as shown in Fig. 7. This figure shows plainly that the edge of one of the T-squares is crooked. This fact, however, does not prove that either one is straight, and for this determination a third blade must be used and tried with the two given T-squares successively.

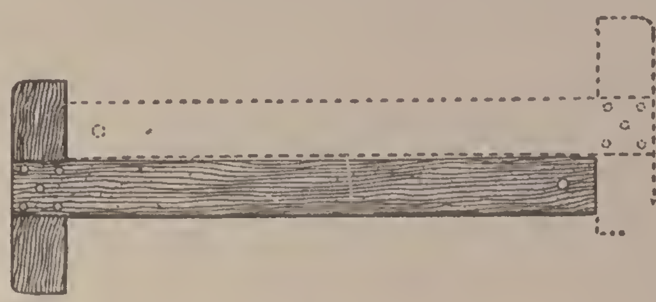


Fig. 7.

Triangles. Triangles are made of various substances such as wood, rubber, celluloid and steel. Wooden triangles are cheap but are likely to warp and get out of shape. The rubber triangles are frequently used, and are in general satisfactory. The transparent celluloid triangle is, however, extensively used on account of its transparency, which enables the draftsmen to see the work already done even when covered with the triangle. In using a rubber or celluloid triangle take care that it lies perfectly flat or


TRIANGLES.

is hung up when not in use; when allowed to lie on the drawing board with a pencil or an eraser under one corner it will become warped in a short time, especially if the room is hot or the sun happens to strike the triangle.

Triangles are made in various sizes, and many draftsmen have several constantly on hand. A triangle from 6 to 8 inches on a side will be found convenient for most work, although there are many cases where a small triangle measuring about 4 inches

on a side will be found useful. Two triangles are necessary for every draftsman, one having two angles of 45 degrees each and one a right angle; and the other having one angle of 60 degrees, one of 30 degrees and one of 90 degrees.

The value of the triangle depends upon the accuracy of the angles and the straightness of the edges. To test the accuracy of the right angle of a triangle, place the triangle with the lower edge resting on the edge of the T-square, as shown in Fig. 8. Now draw the line C D, which should be perpendicular to the edge of the T-square. The same triangle should then be placed in the position shown at B. If the right angle of the triangle is exactly 90 degrees the left-hand edge of the triangle should exactly coincide with the line C D.

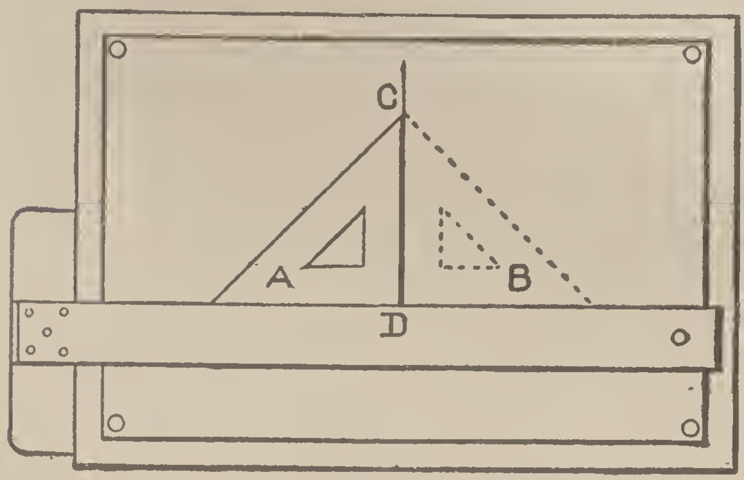


Fig. 8.

To test the accuracy of the 45-degree triangles, first test the right angle then place the triangle with the lower edge resting on the working edge of the T-square, and draw the line E F as shown in Fig. 9. Now without moving the T-square place the triangle so that the other 45-degree angle is in the position occupied by the first. If the two 45-degree angles coincide they are accurate.

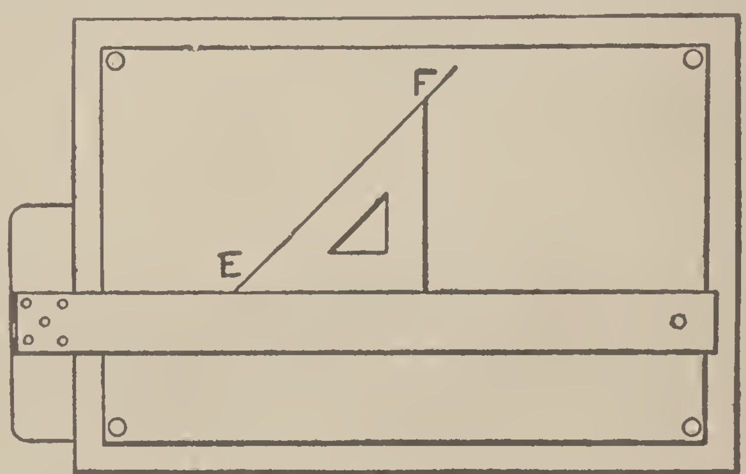


Fig. 9.

Triangles are very convenient in drawing lines at right angles to the T-square. The method of doing this is shown in Fig. 10. Triangles are also used in drawing lines at an angle with the horizontal, by placing them on the board as shown in Fig. 11. Suppose the line E F (Fig. 12) is drawn at any angle, and we wish to draw a line through the point P parallel to it.

First place one of the triangles as shown at A, having one edge coinciding with the given line. Now take the other triangle and place one of its edges in contact with the bottom edge of triangle A. Holding the triangle B firmly with the left hand the triangle A may be slipped along to the right or to the left until the edge of the triangle reaches the point P. The line M N may then be drawn along the edge of the triangle passing through the point P. In place of the triangle B any straight edge such as a T-square may be used.

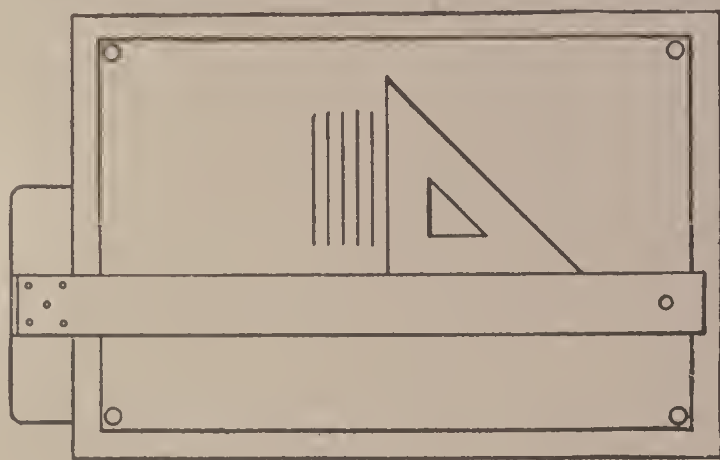


Fig. 10.

A line can be drawn perpendicular to another by means of the triangles as follows. Let E F (Fig. 13) be the given line, and suppose we wish to draw a line perpendicular to E F through the point D. Place the longest side of one of the triangles so that it coincides with the line E F, as the triangle is shown in position at A. Place the other triangle (or any straight edge) in the position of the triangle as shown at B, one edge resting against the edge of the triangle A. Then holding B with the left hand, place the triangle A in the position shown at C, so that the longest side passes through the point D. A line can then be drawn through the point D perpendicular to E F.

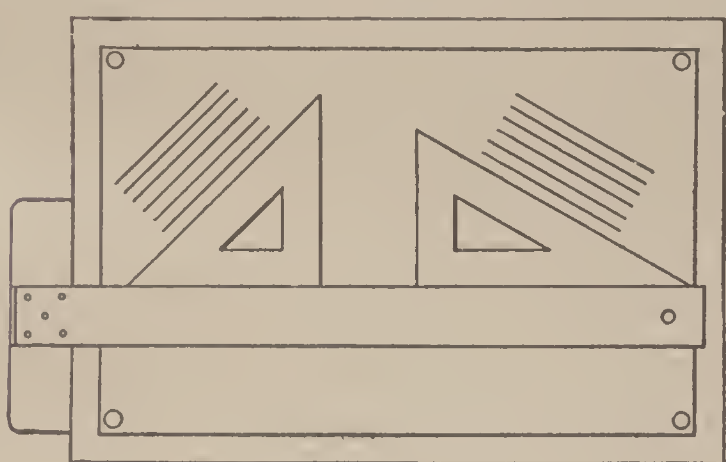


Fig. 11.

In previous figures we have seen how lines may be drawn making angles of 30, 45, 60 and 90 degrees with the horizontal. If it is desired to draw lines forming angles of 15 and 75 degrees the triangles may be placed as shown in Fig. 14.

In using the triangles and T-square almost any line may be drawn. Suppose we wish to draw a rectangle having one side

horizontal. First place the T-square as shown in Fig. 15. By moving the T-square up or down, the sides A B and D C may be drawn, because they are horizontal and parallel. Now place one of the triangles resting on the T-square as shown at E, and having the left-hand edge passing through the poirt D. The vertical

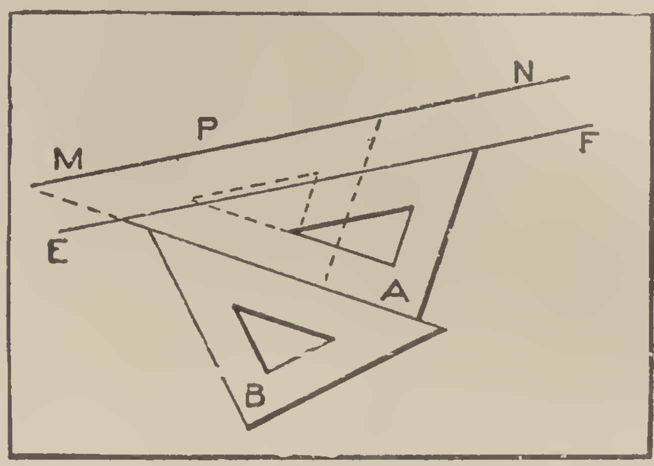


Fig. 12.

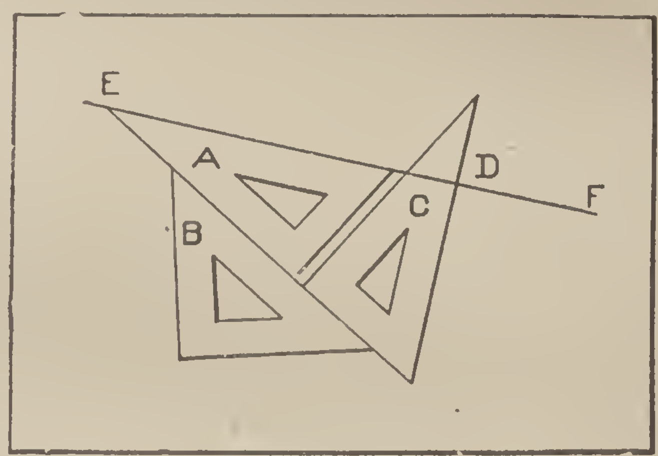


Fig. 13.

line D A may be drawn, and by sliding the triangle along the edge of the T-square to the position F the line B C may be drawn by using the same edge. These positions are shown dotted in Fig. 15.

If the rectangle is to be placed in some other position on the drawing board, as shown in Fig. 16, place the 45-degree triangle F so that one edge is parallel to or coincides with the side D C. Now holding the triangle F in position place the triangle H so that its upper edge coincides with the lower edge of the triangle F. By holding H in position and sliding the triangle F along its upper edge, the sides A B and D C may be drawn. To draw the sides A D and B C the triangle should be used as shown at E.

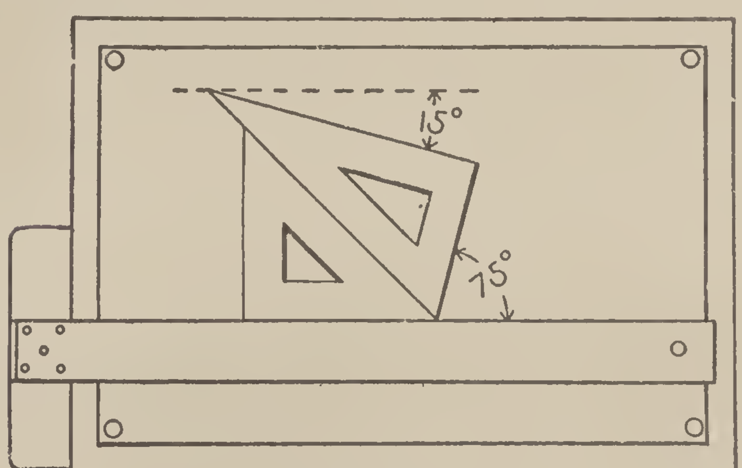


Fig. 14.

Compasses. Compasses are used for drawing circles and arcs of circles. They are made of various materials and in various sizes. The cheaper class of instruments are made of brass, but they are unsatisfactory on account of the odor and the tendency to tarnish. The best material is German silver. It does not soil

readily, it has no odor, and is easy to keep clean. Aluminum instruments possess the advantage of lightness, but on account of the soft metal they do not wear well.

The compasses are made in the form shown in Figs. 17 and 18. Pencil and pen points are provided, as shown in Fig. 17. Either pen or pencil may be inserted in one leg by means of a shank and socket. The other leg is fitted with a needle point which is placed at the center of the circle. In most instruments the needle point is separate, and is made of a piece of round steel wire having a square shoulder at one or both ends. Below this shoulder the needle point projects. The needle is made in this form so that the hole in the paper may be very minute.

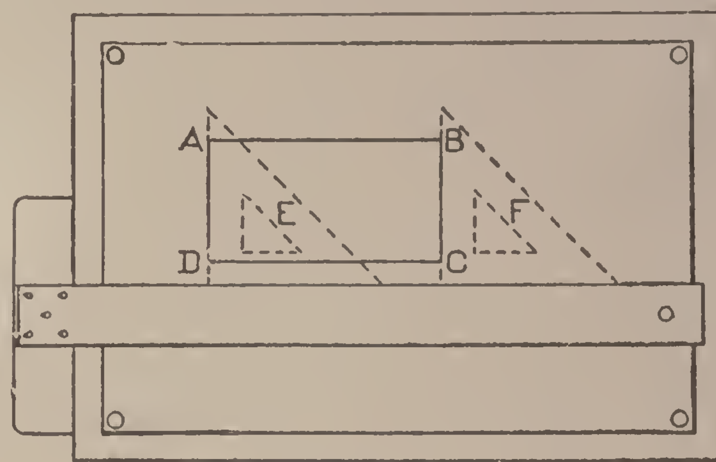


Fig. 15.

In some instruments lock nuts are used to hold the joint firmly in position. These lock nuts are thin discs of steel, with notches for using a wrench or forked key. Fig. 19 shows the detail of the joint of high grade instruments. Both legs are alike at the joint, and two pivoted screws are inserted in the yoke. This permits ample movement of the legs, and at the same time gives the proper stiffness. The flat surface of one of the legs is faced with steel, the other being of German silver, in order that the rubbing parts may be of different metals. Small set screws are used to prevent the pivoted screws from turning in the yoke. The contact surfaces of this joint are made circular to exclude dust and dirt and to prevent rusting of the steel face.

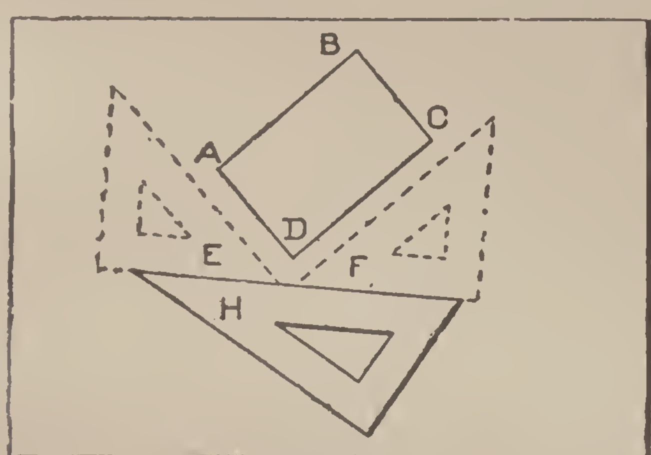


Fig. 16.

Figs. 20, 21 and 22 show the detail of the socket; in some

instruments the shank and socket are pentagonal, as shown in Fig. 20. The shank enters the socket loosely, and is held in place by means of the screw. Unless used very carefully this arrangement is not durable because the sharp corners soon wear, and the pressure on the set screw is not sufficient to hold the shank firmly in place.

In Fig. 21 is shown another form of shank. This is round, having a flat top. A set screw is also used to hold this in position. A still better form of socket is shown in Fig. 22; the hole

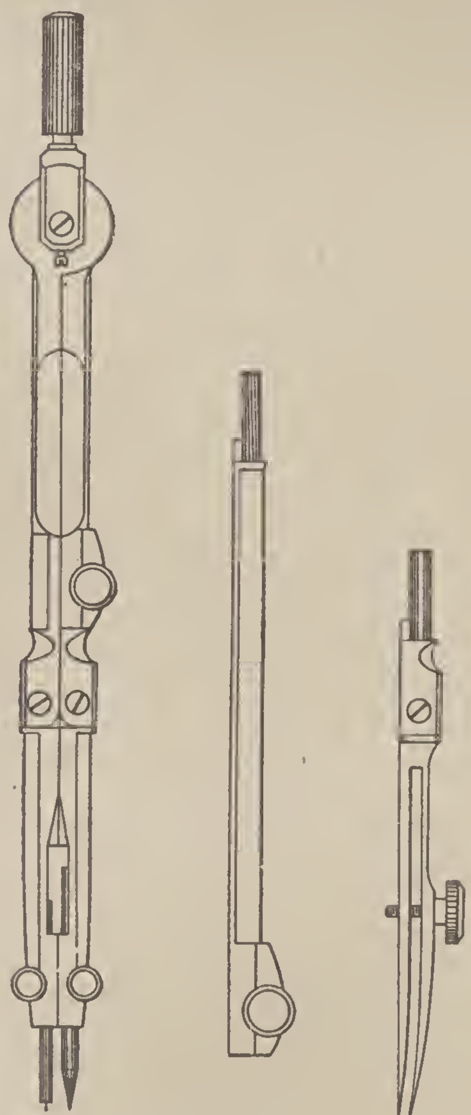


Fig. 17.

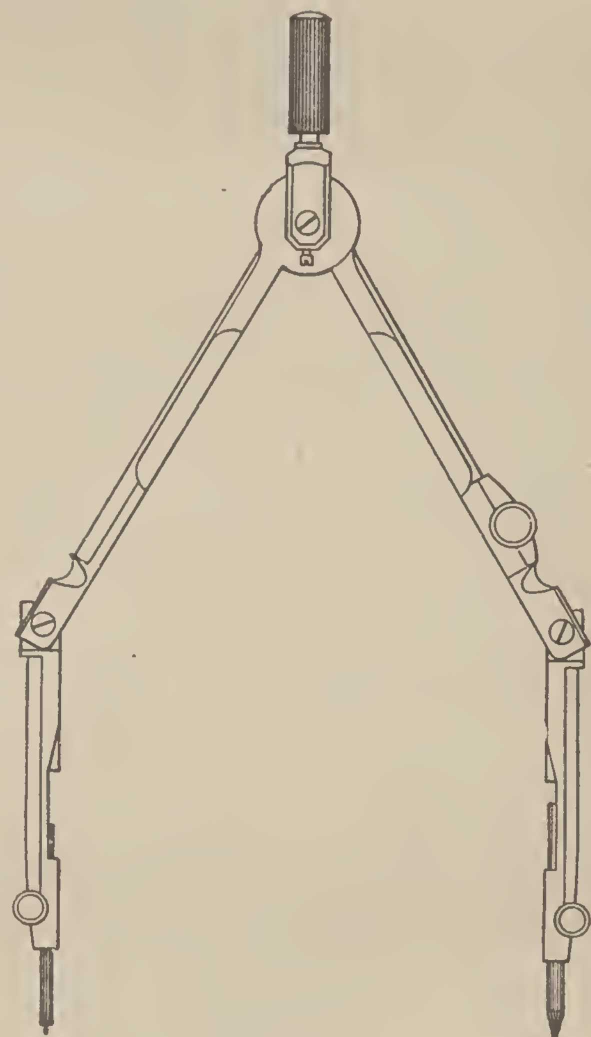


Fig. 18.

is made tapered and is circular. The shank fits accurately, and is held in perfect alignment by a small steel key. The clamping screw is placed upon the side, and keeps the two portions of the split socket together.

Figs. 17 and 18 show that both legs of the compasses are jointed in order that the lower part of the legs may be perpendicular to the paper while drawing circles. In this way the needle point makes but a small hole in the paper, and both nibs of

the pen will press equally on the paper. In pencilling circles it is not as necessary that the pencil should be kept vertical; it is a good plan, however, to learn to use them in this way both in pencilling and inking. The compasses should be held loosely between the thumb and forefinger. If the needle point is sharp, as it should be, only a slight pressure will be required to keep it in place. While drawing the circle, incline the compasses slightly in the direction of revolution and press lightly on the pencil or pen.

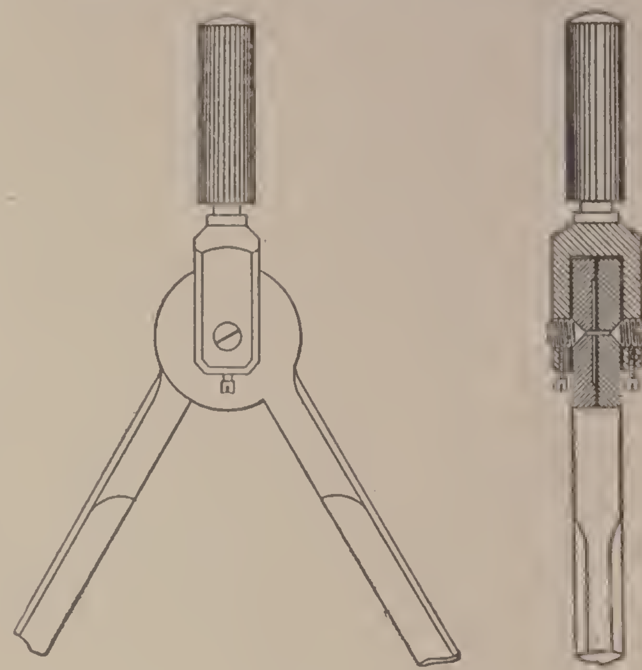


Fig. 19.

In removing the pencil or pen, it should be pulled out straight. If bent from side to side the socket will become enlarged and the shank worn; this will render the instrument inaccurate. For drawing large circles the lengthening bar shown in Fig. 17 should be used. When using the lengthening bar the

Fig. 20.

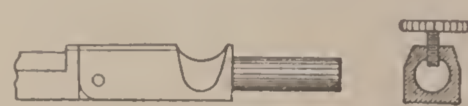


Fig. 21.

needle point should be steadied with one hand and the circle described with the other.

Dividers. Dividers, shown in Fig. 23, are made similar to the compasses. They are used for laying off distances on the drawing, either from scales or from other parts of the drawing. They may also be used for dividing a line into equal parts. When dividing a line into equal parts the dividers should be turned in the opposite direction each time, so that the moving point passes alternately to the right and to the left. The instrument can then be operated readily with one hand. The points of the dividers should be very sharp so that the holes made in the paper will be small. If large holes are made in the paper, and the distances between

Fig. 22.

the points are not exact, accurate spacing cannot be done Sometimes the compasses are furnished with steel divider points in addition to the pen and pencil points. The compasses may then be used either as dividers or as compasses. Many draftsmen use a *needle point* in place of dividers for making measurements from a scale. The eye end of a needle is first broken off and the needle then forced into a small handle made of a round piece of soft pine. This instrument is very convenient for indicating the intersection of lines and marking off distances.

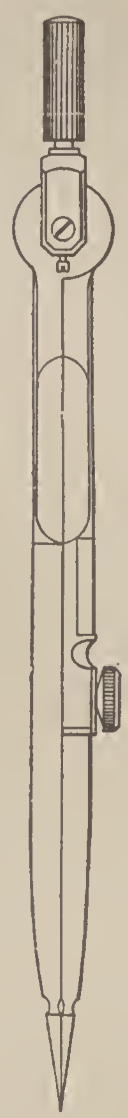


Fig. 23.

Bow Pen and Bow Pencil. Ordinary large compasses are too heavy to use in making small circles, fillets, etc. The leverage of the long leg is so great that it is very difficult to draw small circles accurately. For this reason the bow compasses shown in Figs. 24 and 25 should be used on all arcs and circles having a radius of less than three-quarters inch. The bow compasses are also convenient for duplicating small circles such as those which represent boiler tubes, bolt holes, etc., since there is no tendency to slip.

The needle point must be adjusted to the same length as the pen or pencil point if very small circles are to be drawn. The adjustment for altering the radius of the circle can be made by turning the nut. If the change in radius is considerable the points should be pressed together to remove the pressure from the nut which can then be turned in either direction with but little wear on the threads.

Fig. 26 shows another bow instrument which is frequently used in small work in place of the dividers. It has the advantage of retaining the adjustment.

Drawing Pen. For drawing straight lines and curves that are not arcs of circles, the line pen (sometimes called the ruling pen) is used. It consists of two blades of steel fastened to a handle as shown in Fig. 27. The distance between the pen points can be adjusted by the thumb screw, thus regulating the width of line to be drawn. The blades are given a slight curvature so that there will be a cavity for ink when the points are close together.

The pen may be filled by means of a common steel pen or with the quill which is provided with some liquid inks. The pen should not be dipped in the ink because it will then be necessary to wipe the outside of the blades before use. The ink should fill the pen to a height of about $\frac{1}{4}$ or $\frac{3}{8}$ inch; if too much ink is placed in the pen it is likely to drop out and spoil the drawing. Upon finishing the work the pen should be carefully wiped with

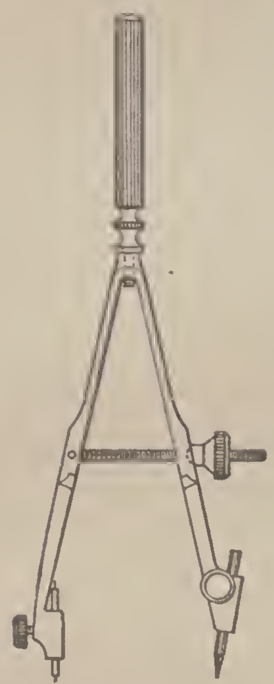


Fig. 24.

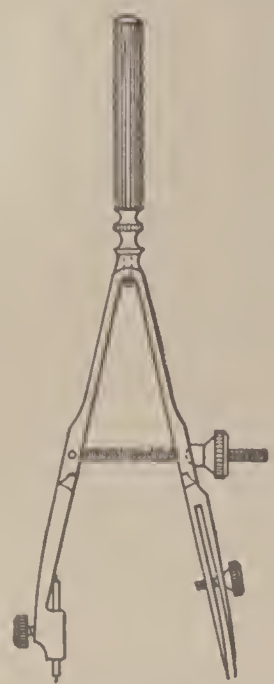


Fig. 25.

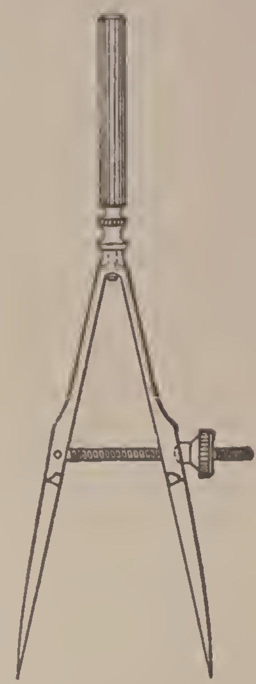


Fig. 26.

chamois or a soft cloth, because most liquid inks corrode the steel.

In using the pen, care should be taken that both blades bear equally on the paper. If the points do not bear equally the line will be ragged. If both points touch, and the pen is in good condition the line will be smooth. The pen is usually inclined slightly in the direction in which the line is drawn. The pen

Fig. 27.

should *touch* the triangle or T-square which serve as guides, but it should not be pressed against them because the lines will then be uneven. The points of the pen should be close to the edge of the triangle or T-square, but should not touch it.

To Sharpen the Drawing Pen. After the pen has been used for some time the points become worn, and it is impossible

to make smooth lines. This is especially true if rough paper is used. The pen can be put in proper condition by sharpening it. To do this take a small, flat, close-grained oil-stone. The blades should first be screwed together, and the points of the pen can be given the proper shape by drawing the pen back and forth over the stone changing the inclination so that the shape of the ends will be parabolic. This process dulls the points but gives them the proper shape, and makes them of the same length.

To sharpen the pen, separate the points slightly and rub one of them on the oil-stone. While doing this keep the pen at an angle of from 10 to 15 degrees with the face of the stone, and give it a slight twisting movement. This part of the operation requires great care as the shape of the ends must not be altered. After the pen point has become fairly sharp the other point should be ground in the same manner. All the grinding should be done on the *outside* of the blades. The burr should be removed from the inside of the blades by using a piece of leather or a piece of pine wood.

Ink should now be placed between the blades and the pen tried. The pen should make a smooth line whether fine or heavy, but if it does not the grinding must be continued and the pen tried frequently.

Ink. India ink is always used for drawing as it makes a permanent black line. It may be purchased in solid stick form or as a liquid. The liquid form is very convenient as much time is saved, and all the lines will be of the same color; the acid in the ink, however, corrodes steel and makes it necessary to keep the pen perfectly clean.

Some draftsmen prefer to use the India ink which comes in stick form. To prepare it for use, a little water should be placed in a saucer and one end of the stick placed in it. The ink is ground by giving it a twisting movement. When the water has become black and slightly thickened, it should be tried. A heavy line should be made on a sheet of paper and allowed to dry. If the line has a grayish appearance, more grinding is necessary. After the ink is thick enough to make a good black line, the grinding should cease, because very thick ink will not flow freely from the pen. If, however, the ink has become too

thick, it may be diluted with water. After using, the stick should be wiped dry to prevent crumbling. It is well to grind the ink in small quantities as it does not dissolve readily if it has once become dry. If the ink is kept covered it will keep for two or three days.

Scales. Scales are used for obtaining the various measurements on drawings. They are made in several forms, the most convenient being the flat with beveled edges and the triangular. The scale is usually a little over 12 inches long and is graduated for a distance of 12 inches. The triangular scale shown in Fig. 28 has six surfaces for graduations, thus allowing many graduations on the same scale.

The graduations on the scales are arranged so that the drawings may be made in any proportion to the actual size. For mechanical work, the common divisions are multiples of two.

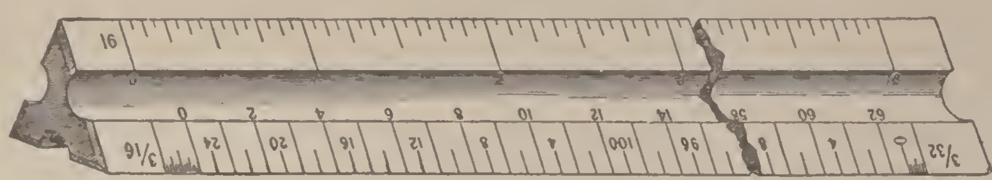


Fig. 28.

Thus we make drawings full size, half size, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, etc. If a drawing is $\frac{1}{4}$ size, 3 inches equals 1 foot, hence 3 inches is divided into 12 equal parts and each division represents one inch. If the smallest division on a scale represents $\frac{1}{16}$ inch, the scale is said to read to $\frac{1}{16}$ inch.

Scales are often divided into $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{30}$, $\frac{1}{40}$, etc., for architects, civil engineers, and for measuring on indicator cards.

The scale should never be used for drawing lines in place of triangles or T-square.

Protractor. The protractor is an instrument used for laying off and measuring angles. It is made of steel, brass, horn and paper. If made of metal the central portion is cut out as shown in Fig. 29, so that the draftsman can see the drawing. The outer edge is divided into degrees and tenths of degrees. Sometimes the graduations are very fine. In using a protractor a very sharp hard pencil should be used so that the lines will be fine and accurate.

The protractor should be placed so that the given line (pro-

duced if necessary) coincides with the two O marks. The center of the circle being placed at the point through which the desired line is to be drawn. The division can then be marked with the pencil point or needle point.

Irregular Curve. One of the conveniences of a draftsman's

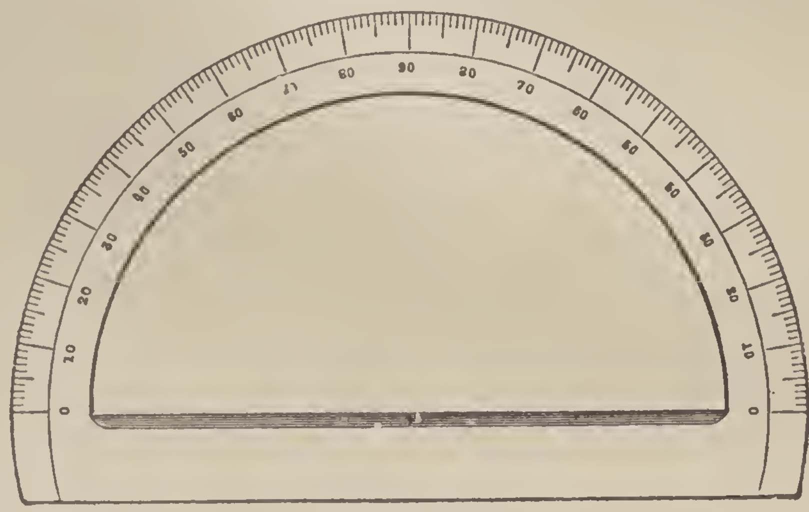


Fig. 29.

outfit is the French or irregular curve. It is made of wood, hard rubber or celluloid, the last named material being the best. It is made in various shapes, two of the most common being

Fig. 30.

shown in Fig. 30. This instrument is used for drawing curves other than arcs of circles, and both pencil and line pen can be used.

To draw the curve, a series of points is first located and then the curve drawn passing through them by using the part of the irregular curve that passes through several of them. The

curve is shifted for this work from one position to another. It frequently facilitates the work and improves its appearance to draw a free hand pencil curve through the points and then use the irregular curve, taking care that it always fits at least *three* points.

In inking the curve, the blades of the pen must be kept

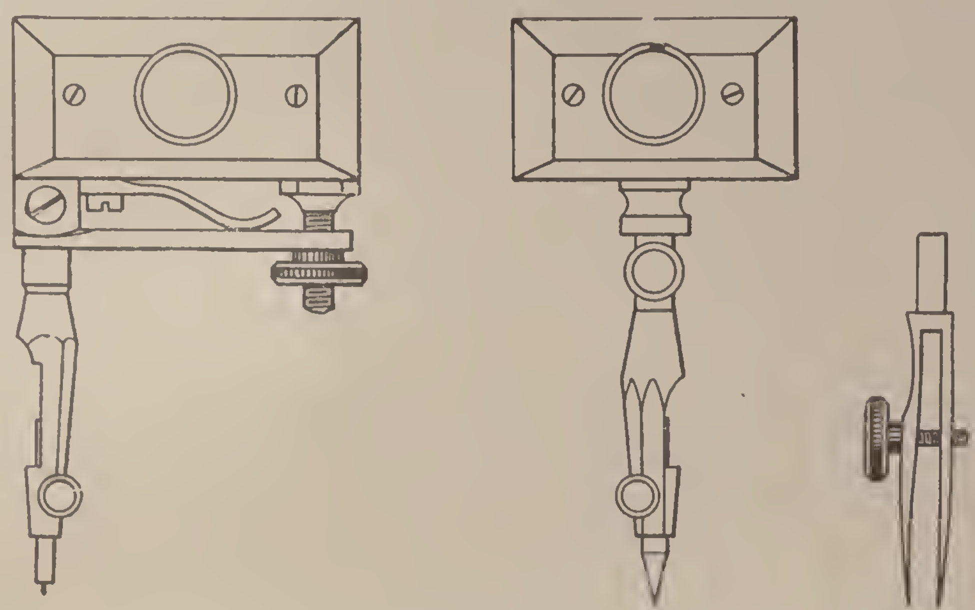


Fig. 31.

tangent to the curve, thus necessitating a continual change of direction.

Beam Compasses. The ordinary compasses are not large enough to draw circles having a diameter greater than about 8 or 10 inches. A convenient instrument for larger circles is found in the beam compasses shown in Fig. 31. The two parts called channels carrying the pen or pencil and the needle point are clamped to a wooden beam; the distance between them being equal to the radius of the circle. Accurate adjustment is obtained by means of a thumb nut underneath one of the channel pieces.

LETTERING.

No mechanical drawing is finished unless all headings, titles and dimensions are lettered in plain, neat type. Many drawings are accurate, well-planned and finely executed but do not present a good appearance because the draftsman did not think it worth while to letter well. Lettering requires time and patience; and if one wishes to letter rapidly and well he must practice.

Usually a beginner cannot letter well, and in order to produce a satisfactory result, considerable practice is necessary. Many

think it a good plan to practice lettering before commencing a drawing. A good writer does not always letter well; a poor writer need not be discouraged and think he can never learn to make a neatly lettered drawing.

In making large letters for titles and headings it is often necessary to use drawing instruments and mechanical aids. The small letters, such as those used for dimensions, names of materials, dates, etc., **should be made free hand.**

There are many styles of letters used by draftsmen. For titles, large Roman capitals are frequently used, although Gothic and block letters also look well and are much easier to make.

ABCDEFGHIJ
KLMNOPQR
STUVWXYZ
1234567890

Fig. 32.

Almost any neat letter free from ornamentation is acceptable in the regular practice of drafting. Fig. 32 shows the alphabet of vertical Gothic capitals. These letters are neat, plain and easily made. The inclined or italicized Gothic type is shown in Fig. 33. This style is also easy to construct, and possesses the advantage that a slight difference in inclination is not apparent. If the vertical lines of the vertical letters incline slightly the inaccuracy is very noticeable.

The curves of the inclined Gothic letters such as those in the *B*, *C*, *G*, *J*, etc., are somewhat difficult to make free hand, especially if the letters are about one-half inch high. In the alphabet shown in Fig. 34, the letters are made almost wholly of

straight lines, the corners only being curved. These letters are very easy to make and are clear cut.

The first few plates of this work will require no titles; the only lettering being the student's name, together with the date and plate number. Later, the student will take up the subject of

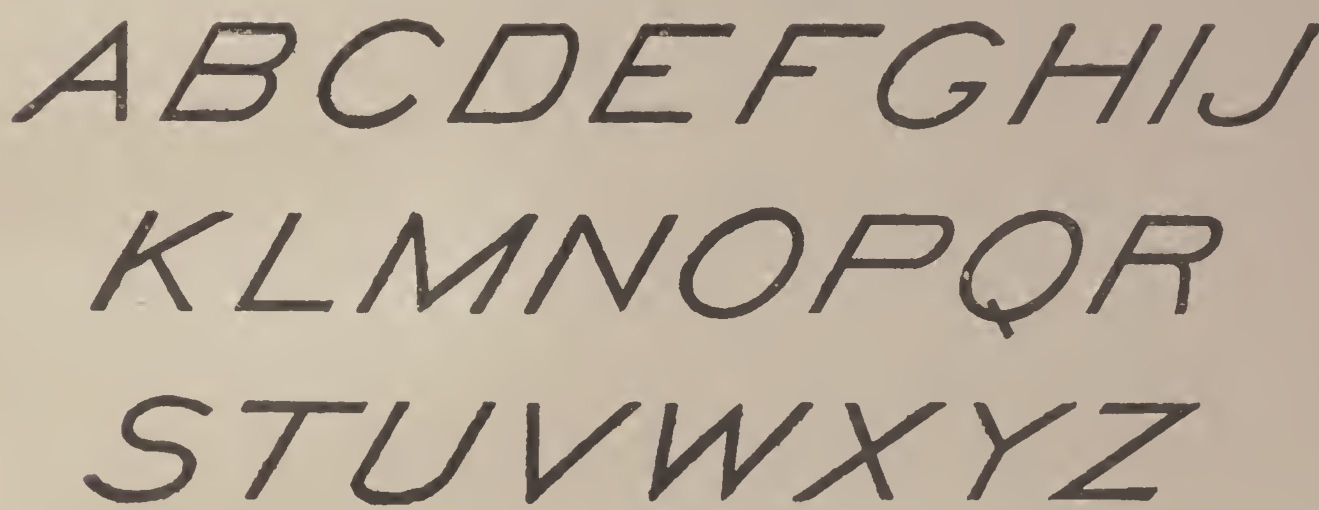


Fig. 33.

lettering again in order to letter titles and headings for drawings showing the details of machines. For the present, however, inclined Gothic capitals will be used.

To make the inclined Gothic letters, first draw two parallel lines having the distance between them equal to the desired height of the letters. If two sizes of letters are to be used, the smaller should be about two-thirds as high as the larger. For the letters

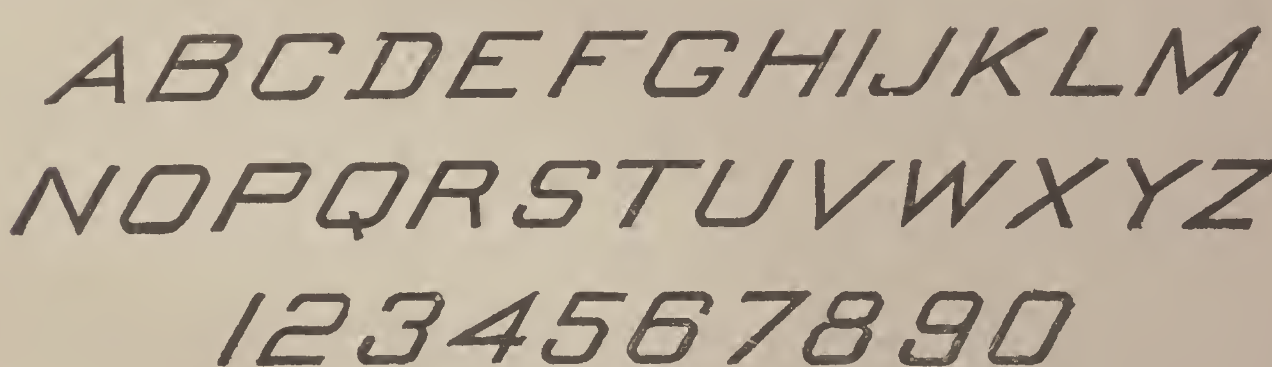


Fig. 34.

to be used on the first plates, draw two parallel lines $\frac{5}{32}$ inch apart. This is the height for the letters of the date, name, also the plate number, and should be used on all plates throughout this work, unless other directions are given.

In constructing the letters, they should extend fully to these lines, both at the top and bottom. They should not fall short of

the guide lines nor extend beyond them. As these letters are inclined they will look better if the inclination is the same for all. As an aid to the beginner, he can draw light pencil lines, about $\frac{1}{4}$ inch apart, forming the proper angle with the parallel lines already drawn. The inclination is often made about 70 degrees; but as a 60-degree triangle is at hand, it may be used. To draw these lines place the 60-degree triangle on the T-square as shown in Fig. 36. In making these letters the 60-degree lines will be found a great aid as a large proportion of the back or side lines have this inclination.

Capital letters such as *E*, *F*, *P*, *T*, *Z*, etc., should have the top lines coincide with the upper horizontal guide line. The bottom lines of such letters as *D*, *E*, *L*, *Z*, etc., should coincide with the lower horizontal guide line. If these lines do not coincide with the guide lines the words will look uneven. Letters, of which *C*, *G*, *O*, and *Q*, are types, can be formed of curved lines or of straight lines. If made of curved lines, they should have a little greater height than the guide lines to prevent their appearing smaller than the other letters. In this work they can be made of straight lines with rounded corners as they are easily constructed and the student can make all letters of the same height.

To construct the letter *A*, draw a line at an angle of 60 degrees to the horizontal and use it as a center line. Then from the intersection of this line and the upper horizontal line drop a vertical line to the lower guide line. Draw another line from the vertex meeting the lower guide line at the same distance from the center line. The cross line of the *A* should be a little below the center. The *V* is an inverted *A* without the cross line. For the letter *M*, the side lines should be parallel and about the same distance apart as are the horizontal lines. The side lines of the *W* are *not* parallel but are farther apart at the top. The *J* is not quite as wide as such letters as *H*, *E*, *N*, *R*, etc. To make a *Y*. draw the center line 60 degrees to the horizontal; the diverging lines are similar to those of the *V* but are shorter and form a larger angle. The diverging lines should meet the center line a little below the middle.

The lower-case letters are shown in Fig. 35. In such letters

as *m*, *n*, *r*, etc., make the corners sharp and not rounding. The letters *a*, *b*, *c*, *e*, *g*, *o*, *p*, *q*, should be full and rounding. The figures (see Fig. 32) are made as in writing — except the *4*, *6*, *8* and *9*.

The Roman numerals are made of straight lines as they are largely made up of *I*, *V* and *X*.

At first the copy should be followed closely and the letters drawn in pencil. For a time, the inclined guide lines may be used.

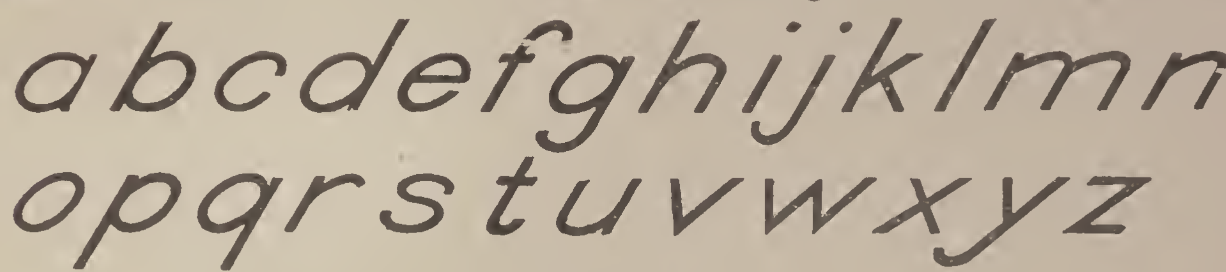


Fig. 35.

but after the proper inclination becomes firmly fixed in mind they should be abandoned. The horizontal lines are used at all times by most draftsmen. After the student has had considerable practice, he can construct the letters in ink without first using the pencil. Later in the work, when the student has become proficient in the simple inclined Gothic capitals, the vertical, block and Roman alphabets should be studied.

PLATES.

To lay out a sheet of paper for the plates of this work, the sheet, A B G F, (Fig. 36) is placed on the drawing board 2 or 3 inches from the left-hand edge which is called the *working edge*. If placed near the left-hand edge, the T-square and triangles can be used with greater firmness and the horizontal lines drawn with the T-square will be more accurate. In placing the paper on the board, always true it up according to the long edge of the sheet. First fasten the paper to the board with thumb tacks, using at least 4 — one at each corner. If the paper has a tendency to curl it is better to use 6 or 8 tacks, placing them as shown in Fig. 36. Thumb tacks are commonly used; but many draftsmen prefer one-ounce tacks as they offer less obstruction to the T-square and triangles.

After the paper is fastened in position, find the center of the

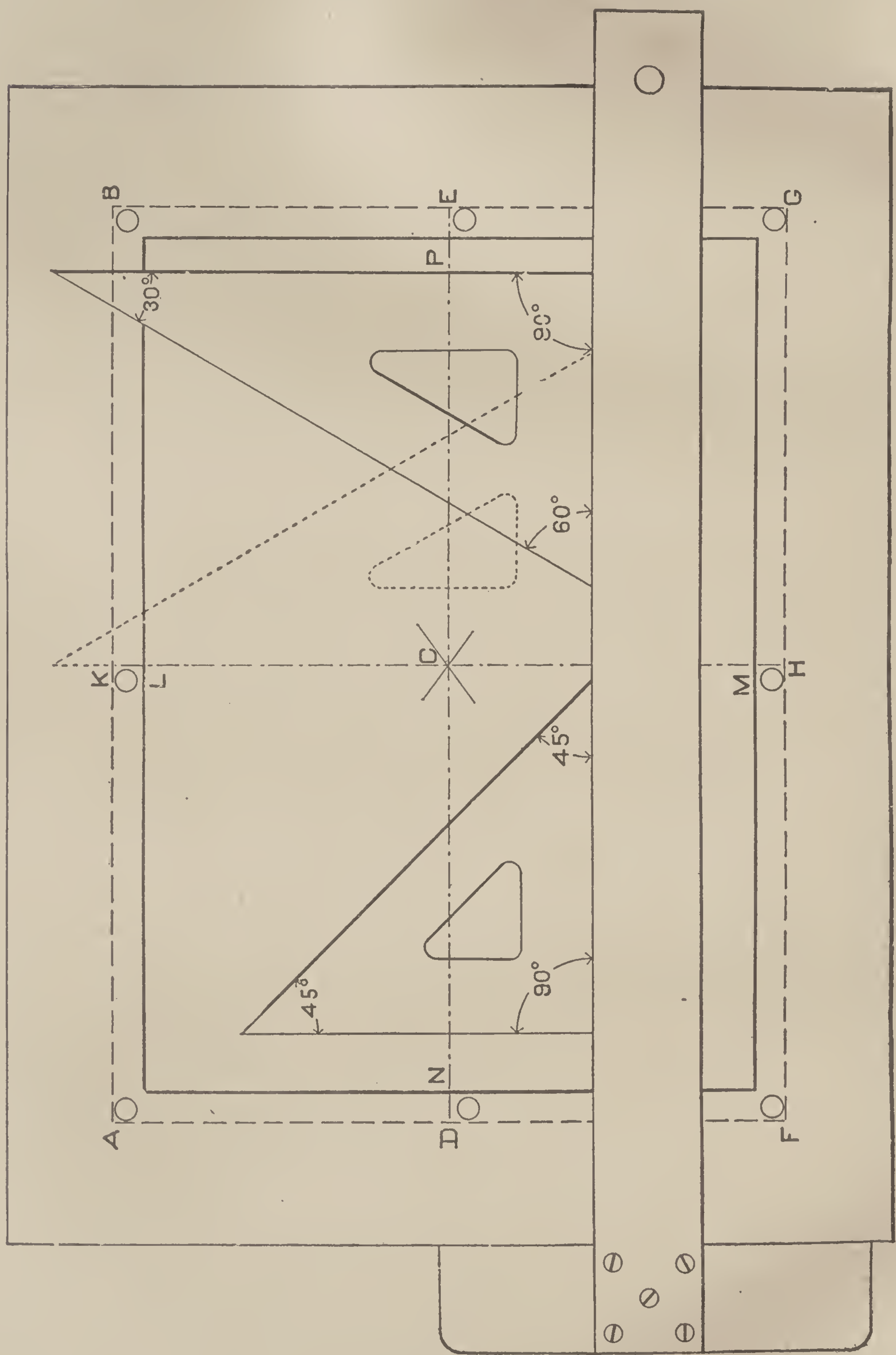


Fig. 36.

sheet by placing the T-square so that its upper edge coincides with the diagonal corners A and G and then with the corners F and B, drawing short pencil lines intersecting at C. Now place the T-square so that its upper edge coincides with the point C and draw the dot and dash line D E. With the T-square and one of the triangles (shown dotted) in the position shown in Fig. 36, draw the dot and dash line H C K. In case the drawing board is large enough, the line C H can be drawn by moving the T-square until it is entirely off the drawing. If the board is small, produce (extend) the line K C to H by means of the T-square or edge of a triangle. In this work always move the pencil from the left to the right or from the bottom upward; never (except for some particular purpose) in the opposite direction.

After the center lines are drawn measure off 5 inches above and below the point C on the line H C K. These points L and M may be indicated by a light pencil mark or by a *slight* puncture of one of the points of the dividers. Now place the T-square against the left-hand edge of the board and draw horizontal pencil lines through L and M.

Measure off 7 inches to the left and right of C on the center line D C E and draw pencil lines through these points (N and P) perpendicular to D E. We now have a rectangle 10 inches by 14 inches, in which all the exercises and figures are to be drawn. The lettering of the student's name and address, date, and plate number are to be placed *outside* of this rectangle in the ½-inch margin. In all cases lay out the plates in this manner and keep the center lines D E and K H as a basis for the various figures. The border line is to be inked with a heavy line when the drawing is inked.

Pencilling. In laying out plates, all work is first done in pencil and afterward inked or traced on tracing cloth. The first few plates of this course are to be done in pencil and then inked; later the subject of tracing and the process of making blue prints will be taken up. Every beginner should practice with his instruments until he can use them with accuracy and skill, and until he understands thoroughly what instrument should be used for making a given line. To aid the beginner in this work, the first three plates of this course are designed to give the student practice; they do

not involve any problems and none of the work is difficult. The student is strongly advised to draw these plates two or three times before making the one to be sent to us for correction. Diligent practice is necessary at first; especially on *PLATE I* as it involves an exercise in lettering.

PLATE I.

Pencilling. To draw *PLATE I*, take a sheet of drawing paper at least 11 inches by 15 inches and fasten it to the drawing board as already explained. Find the center of the sheet and draw fine pencil lines to represent the lines D E and H K of Fig. 36. Also draw the border lines L, M, N and P.

Now measure $\frac{3}{8}$ inch above and below the horizontal center line and, with the T-square, draw lines through these points. These lines will form the lower lines D C of *Figs. 1* and *2* and the top lines A B of *Figs. 3* and *4*. Measure $\frac{3}{8}$ inch to the right and left of the vertical center line; and through these points, draw lines parallel to the center line. These lines should be drawn by placing the triangle on the T-square as shown in Fig. 36. The lines thus drawn, form the sides B C of *Figs. 1* and *3* and the sides A D of *Figs. 2* and *4*. Next draw the line A B A B with the T-square, $4\frac{5}{8}$ inches above the horizontal center line. This line forms the top lines of *Figs. 1* and *2*. Now draw the line D C D C $4\frac{5}{8}$ inches below the horizontal center line. The rectangles of the four figures are completed by drawing vertical lines $6\frac{5}{8}$ inches from the vertical center line. We now have four rectangles each $6\frac{1}{4}$ inches long and $4\frac{1}{4}$ inches wide.

Fig. 1 is an exercise with the line pen and T-square. Divide the line A D into divisions each $\frac{1}{4}$ inch long, making a fine pencil point or *slight* puncture at each division such as E, F, G, H, I, etc. Now place the T-square with the head at the left-hand edge of the drawing board and through these points draw light pencil lines extending to the line B C. In drawing these lines be careful to have the pencil point pass *exactly* through the division marks so that the lines will be the same distance apart. Start each line in the line A D and do not fall short of the line B C or run over it. Accuracy and neatness in pencilling insure an accurate drawing. Some beginners think that they can correct inaccuracies while

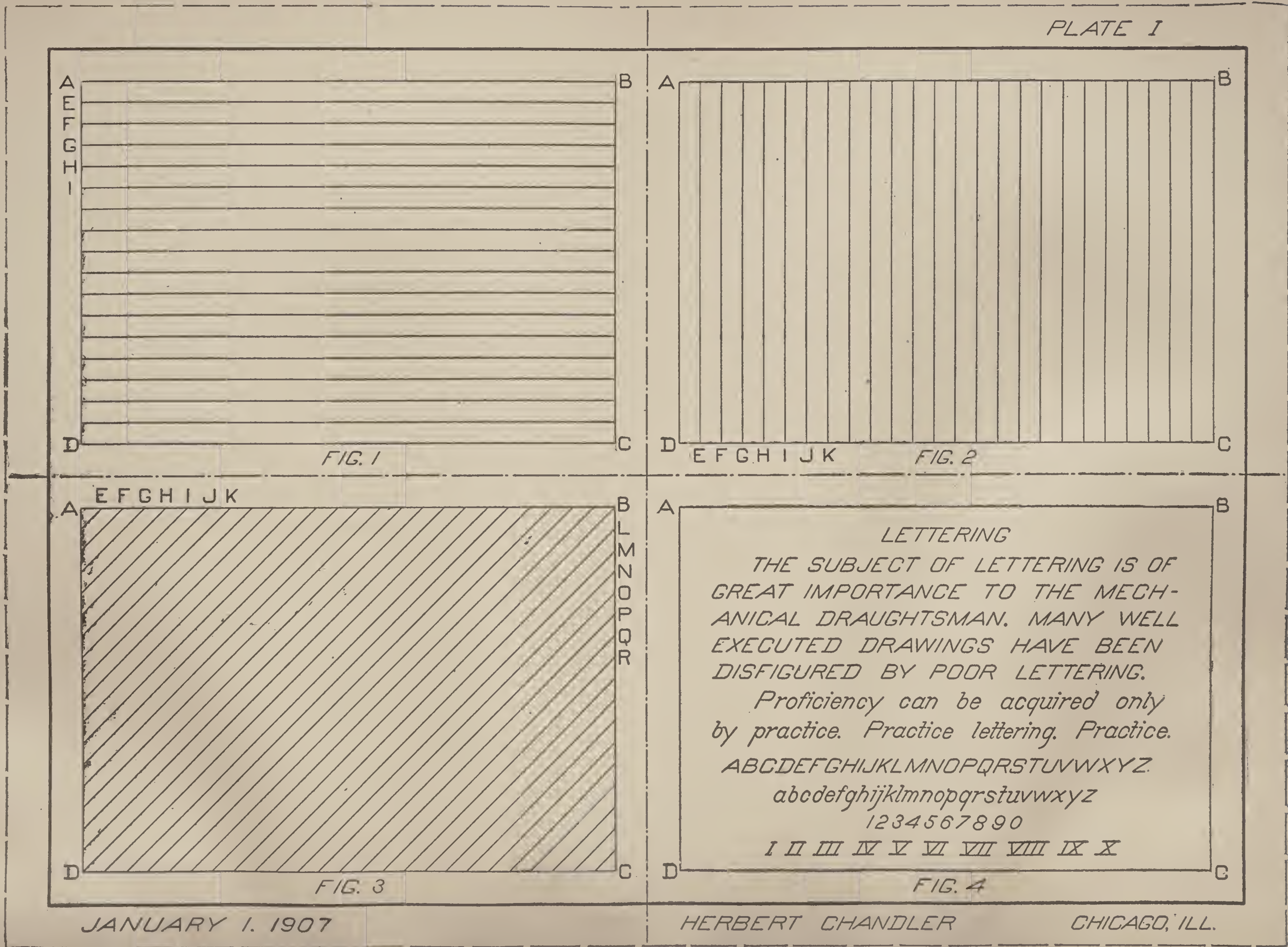


PLATE I
A
E
F
G
H
I
B
D
C
FIG. 1
A
B
D
E F G H I J K
C
FIG. 2
E F G H I J K
A
B
L
M
N
O
P
Q
R
D
C
FIG. 3
A
B
LETTERING
THE SUBJECT OF LETTERING IS OF GREAT IMPORTANCE TO THE MECHANICAL DRAUGHTSMAN. MANY WELL EXECUTED DRAWINGS HAVE BEEN DISFIGURED BY POOR LETTERING.
Proficiency can be acquired only by practice. Practice lettering. Practice.
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890
I II III IV V VI VII VIII IX X
D
C
FIG. 4
JANUARY 1. 1907
HERBERT CHANDLER
CHICAGO, ILL.

inking; but experience soon teaches them that they cannot do so.

Fig. 2 is an exercise with the line pen, T-square and triangle. First divide the lower line D C of the rectangle into divisions each $\frac{1}{4}$ inch long and mark the points E, F, G, H, I, J, K, etc., as in *Fig. 1.* Place the T-square with the head at the left-hand edge of the drawing board and the upper edge in about the position shown in Fig. 36. Place either triangle with one edge on the upper edge of the T-square and the 90-degree angle at the left. Now draw fine pencil lines from the line D C to the line A B passing through the points E, F, G, H, I, J, K, etc. To do this keep the T-square

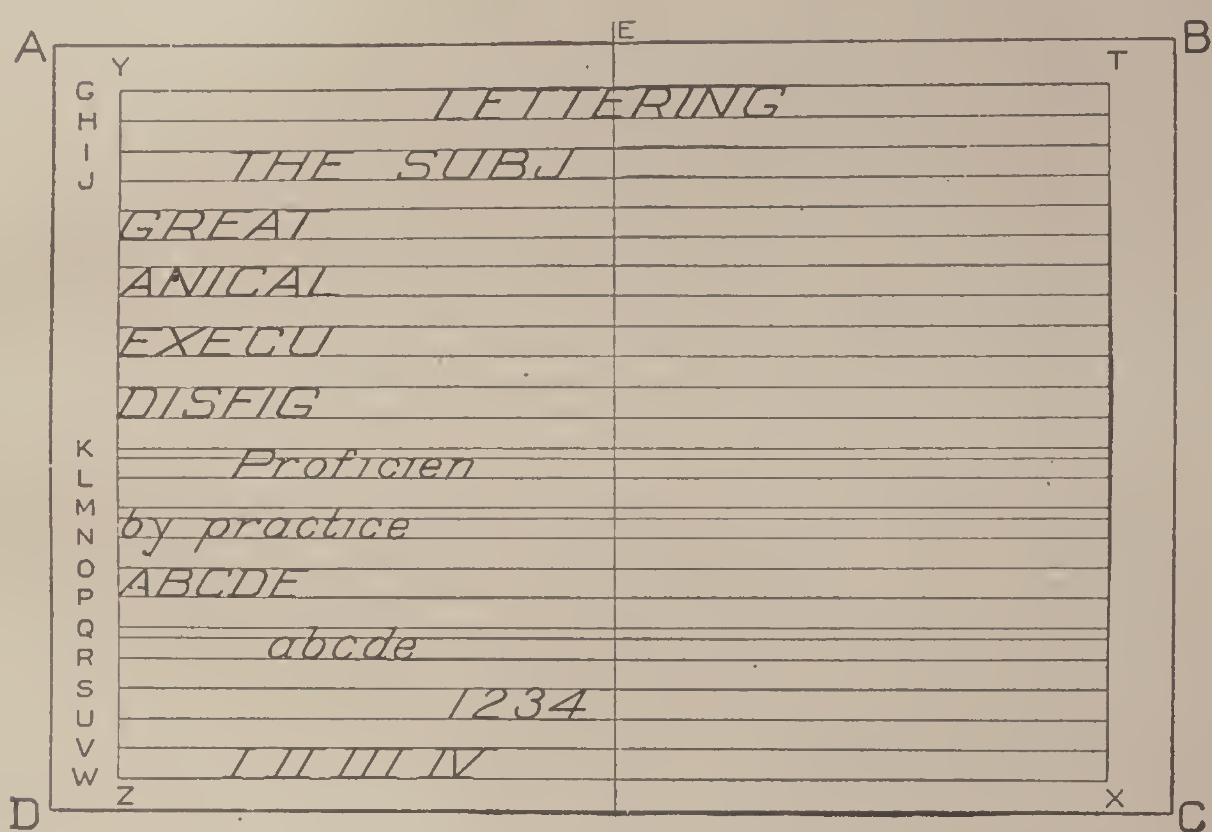


Fig. 37.

rigid and slide the triangle toward the right, being careful to have the edge coincide with the division marks in succession.

Fig. 3 is an exercise with the line pen, T-square and 45-degree triangle. First lay off the distances A E, E F, F G, G H, H I, I J, J K, etc., each $\frac{1}{4}$ inch long. Then lay off the distances B L, L M, M N, N O, O P, P Q, Q R, etc., also $\frac{1}{4}$ inch long. Place the T-square so that the upper edge will be below the line D C of *Fig. 3.* With the 45-degree triangle draw lines from A D and D C to the points E, F, G, H, I, J, K, etc., as far as the point B. Now draw lines from D C to the points L, M, N, O, P, Q, R, etc., as

far as the point C. In drawing these lines move the pencil away from the body, that is, from A D to A B and from D C to B C.

Fig. 4 is an exercise in free-hand lettering. The finished exercise, with all guide lines erased, should have the appearance shown in *Fig. 4* of *PLATE I.* The guide lines are drawn as shown in Fig. 37. First draw the center line E F and light pencil lines Y Z and T X, $\frac{3}{8}$ inch from the border lines. Now, with the T-square, draw the line G, $\frac{1}{4}$ inch from the top line and the line H, $\frac{5}{32}$ inch below G. The word "*LETTERING*" is to be placed between these two lines. Draw the line I, $\frac{3}{16}$ inch below H. The lines I, J, etc., to K are all $\frac{5}{32}$ inch apart.

We now practice the lower-case letters. Draw the line L, $\frac{3}{16}$ inch below K and a light line $\frac{1}{8}$ inch above L to limit the height of the small letters. The space between L and M is $\frac{5}{32}$ inch. The lines M and N are drawn in the same manner as K and L. The space between N and O should be $\frac{1}{4}$ inch. The line P is drawn $\frac{5}{32}$ inch below O. Q is also $\frac{5}{32}$ inch below P. The lines Q and R are drawn $\frac{3}{16}$ inch apart as are M and N. The remainder of the lines S, U, V and W are drawn $\frac{5}{32}$ inch apart.

The center line is a great aid in centering the word "*LETTERING*," the alphabets, numerals, etc. The words "*THE*" and "*Proficiency*" should be indented about $\frac{3}{8}$ inch as they are the first words of paragraphs. To draw the guide lines, mark off distances of $\frac{1}{4}$ inch on any line such as J and with the 60-degree triangle draw light pencil lines cutting the parallel lines. The letters should be sketched in pencil, the ordinary letters such as E, F, H, N, R, etc. being made of a width equal to about $\frac{3}{4}$ the height. Letters like A, M and W are wider. The space between the letters depends upon the draftsman's taste but the beginner should remember that letters next to an A or an L should be placed near them and that greater space should be left on each side of an I or between letters whose sides are parallel; for instance there should be more space between an N and E than between an E and H. On account of the space above the lower line of the L, a letter following an L should be close to it. If a T follows a T or the letter L follows an L they should be placed near together. In all lettering the letters should be placed so that the general effect is pleasing. After the four figures are

completed, the lettering for name, address and date should be pencilled. With the T-square draw a pencil line $\frac{5}{32}$ inch above the top border line at the right-hand end. This line should be about 3 inches long. At a distance of $\frac{5}{32}$ inch above this line draw another line of about the same length. These are the guide lines for the word *PLATE I.* The letters should be pencilled free hand and the student may use the 60-degree guide lines if he desires.

The guide lines of the date, name and address are similarly drawn in the lower margin. The date of completing the drawing should be placed under *Fig. 3* and the name and address at the right under *Fig. 4*. The street address is unnecessary. It is a good plan to draw lines $\frac{5}{32}$ inch apart on a separate sheet of paper and pencil the letters in order to know just how much space each word will require. The insertion of the words "*Fig. 1*," "*Fig. 2*," etc., is optional with the student. He may leave them out if he desires; but we would advise him to do this extra lettering for the practice and for convenience in reference. First draw with the T-square two parallel line $\frac{5}{32}$ inch apart under each exercise; the lower line being $\frac{1}{16}$ inch above the horizontal center line or above the lower border line.

Inking. After all of the pencilling of *PLATE I* has been completed the exercises should be inked. The pen should first be examined to make sure that the nibs are clean, of the same length and come together evenly. To fill the pen with ink use an ordinary steel pen or the quill in the bottle, if Higgin's Ink is used. Dip the quill or pen into the bottle and then inside between the nibs of the line pen. The ink will readily flow from the quill into the space between the nibs as soon as it is brought in contact. Do not fill the pen too full, if the ink fills about $\frac{1}{4}$ the distance to the adjusting screw it usually will be sufficient. If the filling has been carefully done it will not be necessary to wipe the outsides of the blades. However, any ink on the outside should be wiped off with a soft cloth or a piece of chamois.

The pen should now be tried on a separate piece of paper in order that the width of the line may be adjusted. In the first work where no shading is done, a firm distinct line should be used. The beginner should avoid the extremes; a very light line makes

the drawing have a weak, indistinct appearance, and very heavy lines detract from the artistic appearance and make the drawing appear heavy.

In case the ink does not flow freely, wet the finger and touch it to the end of the pen. If it then fails to flow, draw a slip of thin paper between the nibs (thus removing the dried ink) or clean thoroughly and fill. Never lay the pen aside without cleaning.

In ruling with the line pen it should be held firmly in the right hand almost perpendicular to the paper. If grasped too firmly the width of the line may be varied and the draftsman soon becomes fatigued. The pen is usually held so that the adjusting screw is away from the T-square, triangles, etc. Many draftsmen incline the pen slightly in the direction in which it is moving.

To ink *Fig. 1*, place the T-square with the head at the working edge as in pencilling. First ink all of the horizontal lines moving the T-square from A to D. In drawing these lines considerable care is necessary; both nibs should touch the paper and the pressure should be uniform. Have sufficient ink in the pen to finish the line as it is difficult for a beginner to stop in the middle of the line and after refilling the pen make a smooth continuous line. While inking the lines A, E, F, G, H, I, etc., greater care should be taken in starting and stopping than while pencilling. Each line should start *exactly* in the pencil line A D and stop in the line B C. The lines A D and B C are inked, using the triangle and T-square.

Fig. 2 is inked in the same manner as it was pencilled; the lines being drawn, sliding the triangle along the T-square in the successive positions.

In inking *Fig. 3*, the same care is necessary as with the preceding, and after the oblique lines are inked the border lines are finished. In *Fig. 4* the border lines should be inked in first and then the border lines of the plate. The border lines should be quite heavy as they give the plate a better appearance. The intersections should be accurate, as any running over necessitates erasing.

The line pen may now be cleaned and laid aside. It can be

PLATE II

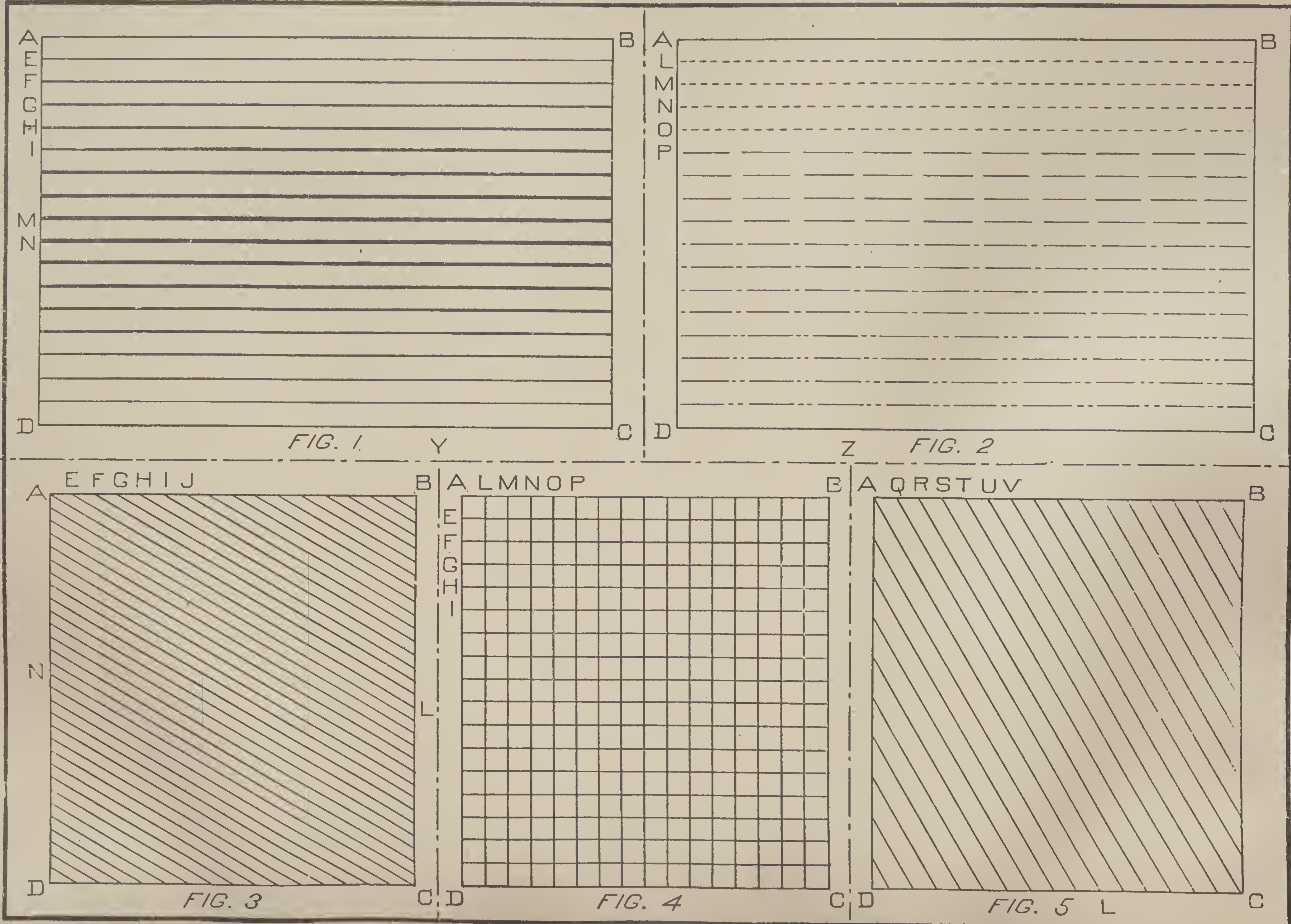


FIG. 1.

FIG. 2

FIG. 3

FIG. 4

FIG. 5

JANUARY 9, 1907 HERBERT CHANDLER CHICAGO, ILL.

cleaned by drawing a strip of blotting paper between the nibs or by means of a piece of cloth or chamois. The lettering should be done free-hand using a steel pen. If the pen is very fine, accurate work may be done but the pen is likely to catch in the paper, especially if the paper is rough. A coarser pen will make broader lines but is on the whole preferable. Gillott's 404 is as fine a pen as should be used. After inking *Fig. 4*, the plate number, date and name should be inked, also free-hand. After inking the words "*Fig. 1*," "*Fig. 2*," etc., all pencil lines should be erased. **In the finished drawing there should be no center lines, construction lines or letters other than those in the name, date, etc.**

The sheet should be cut to a size of 11 inches by 15 inches, the dash line outside the border line of *PLATE I* indicating the edge.

PLATE II.

Pencilling. The drawing paper used for *PLATE II* should be laid out as described with *PLATE I*, that is, the border lines, center line and rectangles for *Figs. 1* and *2*. To lay out *Figs. 3*, *4* and *5* proceed as follows: Draw a line with the T-square parallel to the horizontal center line and $\frac{3}{8}$ inch below it. Also draw another similar line $4\frac{5}{8}$ below the center line. The two lines will form the top and bottom of *Figs. 3*, *4* and *5*. Now measure off $2\frac{1}{4}$ inches on either side of the center on the horizontal center line and call the points Y and Z. On either side of Y and Z and at a distance of $\frac{1}{4}$ inch draw vertical parallel lines. Now draw a vertical line A D, $4\frac{1}{4}$ inches from the line Y and a vertical line B C $4\frac{1}{4}$ inches from the line Z. We now have three rectangles each 4 inches broad and $4\frac{1}{4}$ inches high. *Figs. 1* and *2* are pencilled in exactly the same way as was *Fig. 1* of *PLATE I*, that is, horizontal lines are drawn $\frac{1}{4}$ inch apart.

Fig. 3 is an exercise to show the use of a 60-degree triangle with a T-square. Lay off the distances A E, E F, F G, G H, etc. to B each $\frac{1}{4}$ inch. With the 60 degree triangle resting on the upper edge of the T-square, draw lines through these points, E, F, G, H, I, J, etc., forming an angle of 30 degrees with the horizontal. The last line drawn will be A L. In drawing these lines move the pencil from A B to B C. Now find the distance

between the lines on the vertical B L and mark off these distances on the line B C commencing at L. Continue the lines from A L to N C. Commencing at N mark off distances on A D equal to those on B C and finish drawing the oblique lines.

Fig. 4 is an exercise for intersection. Lay off distances of $\frac{1}{4}$ inch on A B and A D. With the T-square draw fine pencil lines through the points E, F, G, H, I, etc., and with the T-square and triangle draw vertical lines through the points L, M, N, O, P, etc. In drawing this figure draw every line exactly through the points indicated as the symmetrical appearance of the small squares can be attained only by accurate pencilling.

The oblique lines in *Fig. 5* form an angle of 60 degrees with the horizontal. As in *Figs. 3* and *4* mark off the line A B in divisions of $\frac{1}{4}$ inch and draw with the T-square and 60-degree triangle the oblique lines through these points of division moving the pencil from A B to B C. The last line thus drawn will be A L. Now mark off distances of $\frac{1}{4}$ inch on C D beginning at L. The lines may now be finished.

Inking. *Fig. 1* is designed to give the beginner practice in drawing lines of varying widths. The line E is first drawn. This line should be rather fine but should be clear and distinct. The line F should be a little wider than E; the greater width being obtained by turning the adjusting screw from one-quarter to one-half a turn. The lines G, H, I, etc., are drawn; each successive line having greater width. M and N should be the same and quite heavy. From N to D the lines should *decrease* in width. To complete the inking of *Fig. 1*, draw the border lines. These lines should have about the same width as those in *PLATE I.*

In *Fig. 2* the first four lines should be dotted. The dots should be uniform in length (about $\frac{1}{16}$ inch) and the spaces also uniform (about $\frac{1}{32}$ inch). The next four lines are dash lines similar to those used for dimensions. These lines should be drawn with dashes about $\frac{3}{4}$ inch long and the lines should be fine, yet distinct.

The following four lines are called dot and dash lines. The dashes are about $\frac{3}{4}$ inch long and a dot between as shown. In the regular practice of drafting the length of the dashes depends upon the size of the drawing — $\frac{1}{2}$ inch to 1 inch being common. The last four lines are similar, two dots being used between the

dashes. After completing the dot and dash lines, draw the border lines of the rectangle as before.

In inking *Fig. 3*, the pencil lines are followed. Great care should be exercised in starting and stopping. The lines should begin in the border lines and the end should not run over.

The lines of *Fig. 4* must be drawn carefully, as there are so many intersections. The lines in this figure should be lighter than the border lines. If every line does not coincide with the points of division L, M, N, O, P, etc., some will appear farther apart than others.

Fig. 5 is similar to *Fig. 3*, the only difference being in the angle which the oblique lines make with the horizontal.

After completing the five figures draw the border lines of the plate and then letter the plate number, date and name, and the figure numbers, as in *PLATE I.* **The plate should then be cut to the required size, 11 inches by 15 inches.**

PLATE III.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE III* are laid out in the same manner as were those of *PLATE II.* To draw the squares for the six figures, proceed as follows:

Measure off two inches on either side of the vertical center line and draw light pencil lines through these points parallel to the vertical center line. These lines will form the sides A D and B C of *Figs. 2* and *5*. Parallel to these lines and at a distance of $\frac{1}{2}$ inch draw similar lines to form the sides B C of *Figs. 1* and *4* and A D of *Figs. 3* and *6*. The vertical sides A D of *Figs. 1* and *4* and B C of *Figs. 3* and *6* are formed by drawing lines perpendicular to the horizontal center line at a distance of $6\frac{1}{2}$ inches from the center.

The horizontal sides D C of *Figs. 1*, *2* and *3* are drawn with the T-square $\frac{1}{2}$ inch above the horizontal center line. To draw the top lines of these figures, draw (with the T-square) a line $4\frac{1}{2}$ inches above the horizontal center line. The top lines of *Figs. 4*, *5* and *6* are drawn $\frac{1}{2}$ inch below the horizontal center line. The squares are completed by drawing the lower lines D C, $4\frac{1}{2}$ inches below the horizontal center line. The figures of *PLATES I* and *II*

were constructed in rectangles; the exercises of *PLATE III* are, however, drawn in squares, having the sides 4 inches long.

In drawing *Fig. 1*, first divide A D and A B (or D C) into 4 equal parts. As these lines are four inches long, each length will be 1 inch. Now draw horizontal lines through E, F and G and vertical lines through L, M and N. These lines are shown dotted in *Fig. 1.* Connect A and B with the intersection of lines E and M, and A and D with the intersection of lines F and L. Similarly draw D J, J C, I B and I C. Also connect the points P, O, I and J forming a square. The four diamond shaped areas are formed by drawing lines from the middle points of A D, A B, B C and D C to the middle points of lines A P, A O, O B, I B etc., as shown in *Fig. 1.*

Fig. 2 is an exercise of straight lines. Divide A D and A B into four equal parts and draw horizontal and vertical lines as in *Fig. 1.* Now divide these dimensions, A L, M N, etc. and E F, G B etc. into four equal parts (each $\frac{1}{4}$ inch). Draw light pencil lines with the T-square and triangle as shown in *Fig. 2.*

In *Fig. 3*, divide A B and A D into eight parts, each length being $\frac{1}{2}$ inch. Through the points H, I, J, K, L, M and N draw vertical lines with the triangle. Through O, P, Q, R, S, T and U draw horizontal lines with the T-square. Now draw lines connecting O and H, P and I, Q and J, etc. These lines can be drawn with the 45-degree triangle, as they form an angle of 45 degrees with the horizontal. Starting at N draw lines from A B to B C at an angle of 45 degrees. Also draw lines from A D to D C through the points O, P, Q, R, etc., forming angles of 45 degrees with D C.

Fig. 4 is drawn with the compasses. First draw the diagonals A C and D B. With the T-square draw the line E H. Now mark off on E H distances of $\frac{1}{4}$ inch. With the compasses set so that the point of the lead is 2 inches from the needle point, describe the circle passing through E. With H as a center draw the arcs F G and I J having a radius of $1\frac{3}{4}$ inches. In drawing these arcs be careful not to go beyond the diagonals, but stop at the points F and G and I and J. Again with H as the center and a radius of $1\frac{1}{2}$ inches draw a circle. The arcs K L and M N are drawn in the same manner as were arcs F G and I J; the

PLATE III

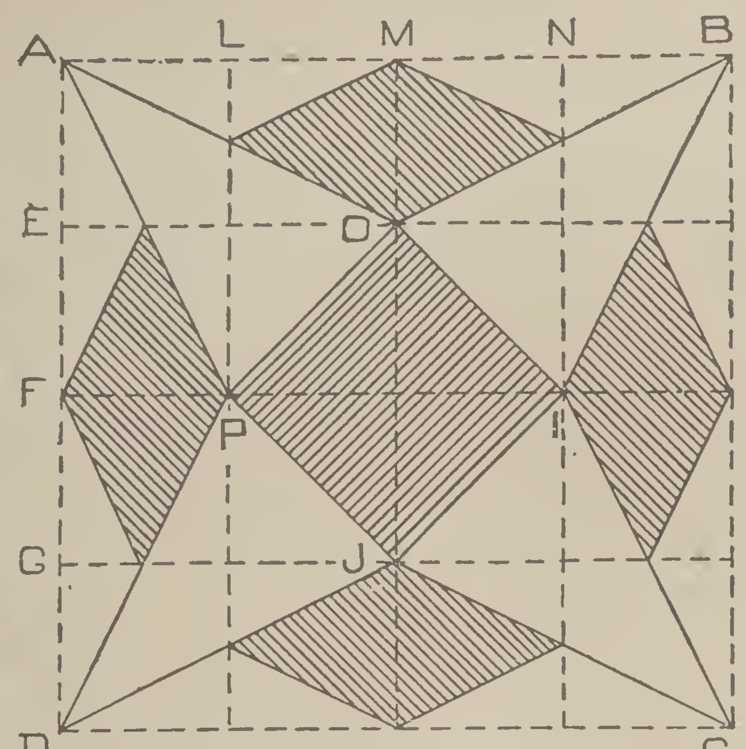


FIG 1

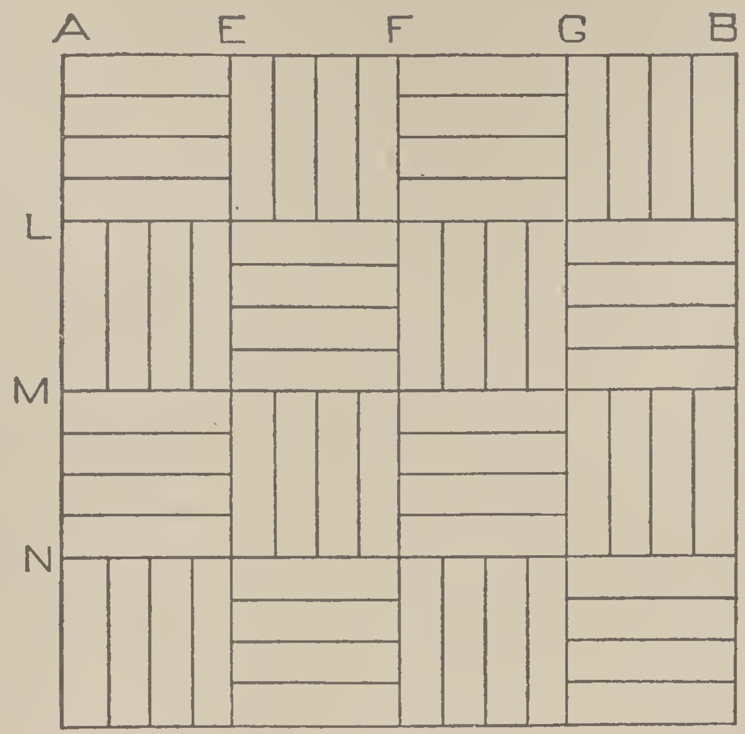


FIG. 2

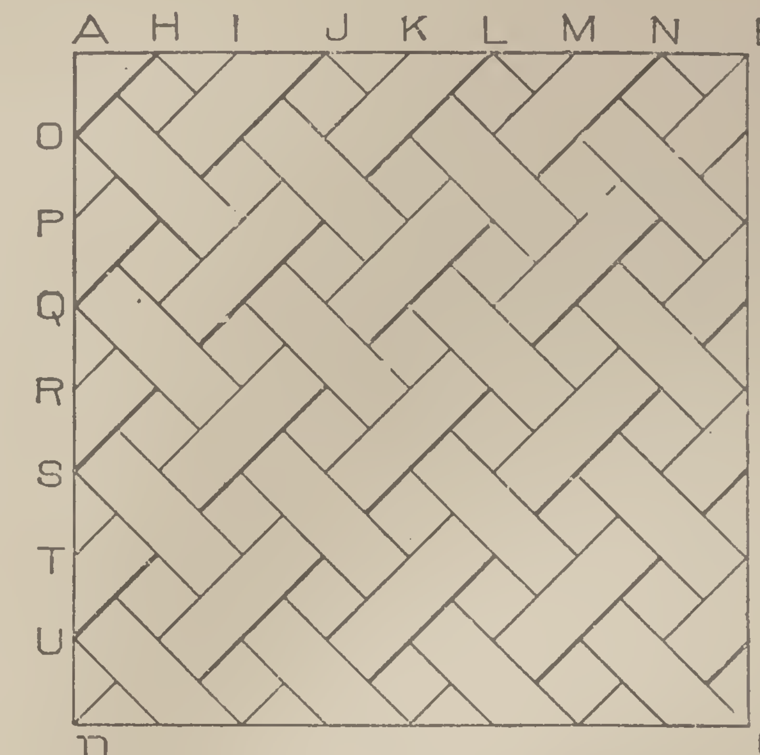


FIG. 3

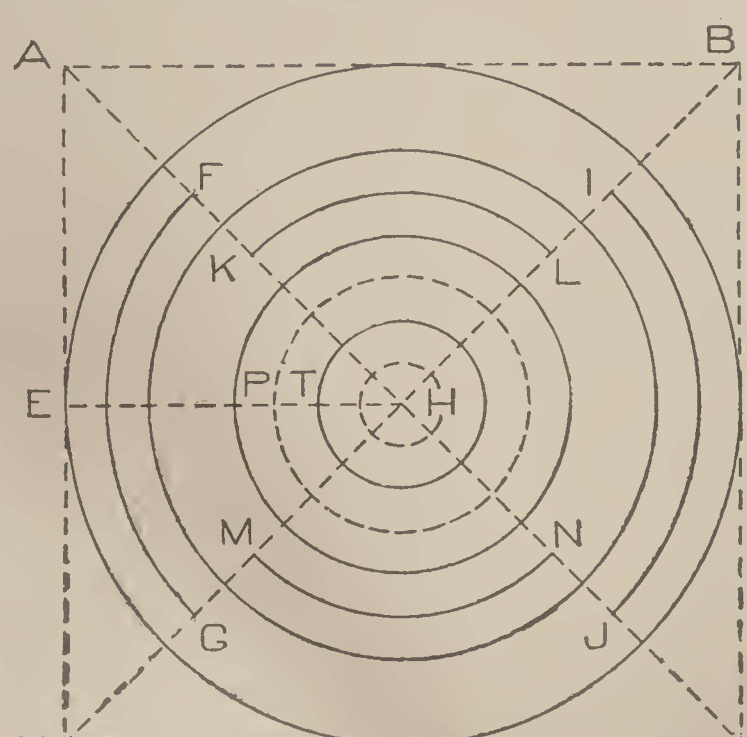


FIG. 4

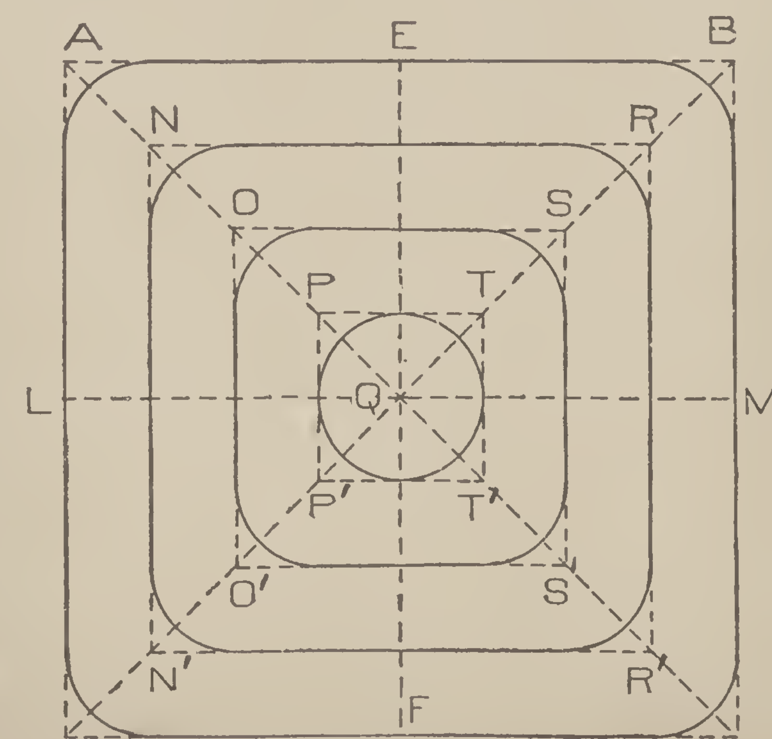


FIG. 5

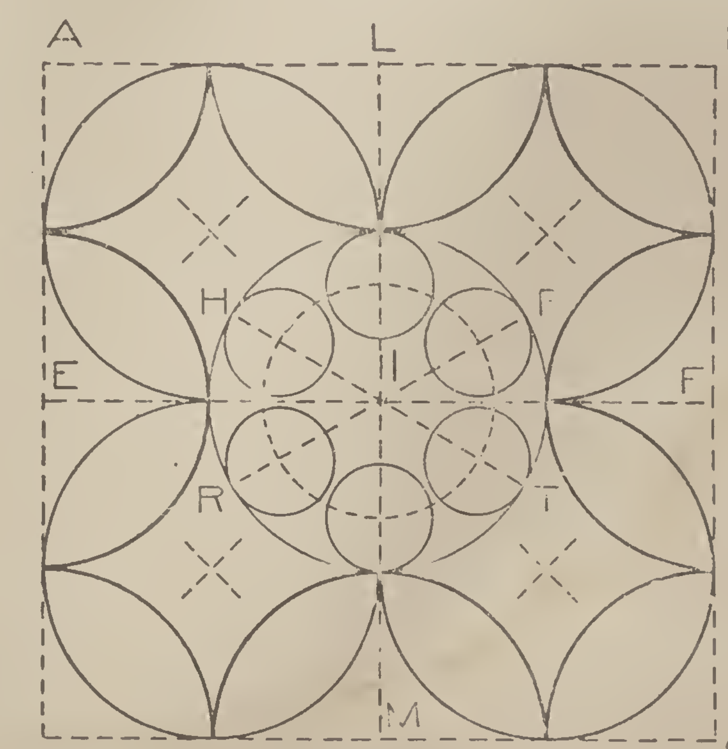


FIG. 6

JANUARY 14, 1907 HERBERT CHANDLER CHICAGO, ILL.

radius being $1\frac{1}{4}$ inches. Now draw circles, with H as the center, of 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ inch radius, passing through the points P, T, etc.

Fig. 5 is an exercise with the line pen and compasses. First draw the diagonals A C and D B, the horizontal line L M and the vertical line E F passing through the center Q. Mark off distances of $\frac{1}{2}$ inch on L M and E F and draw the lines N N′ O O′ and N R, O S, etc., through these points, forming the squares N R R′ N′, O S S′ O′, etc. With the bow pencil adjusted so that the distance between the pencil point and the needle point is $\frac{1}{2}$ inch draw the arcs having centers at the corners of the squares. The arc whose center is N will be tangent to the lines A L and A E and the arc whose center is O will be tangent to N N′ and N R. Since P T, T T′, T′ P′ and P′ P are each 1 inch long and form the square, the arcs drawn with Q as a center will form a circle.

To draw *Fig. 6*, first draw the center lines E F and L M. Now find the centers of the small squares A L I E, L B F I etc. Through the center I draw the construction lines H I T and R I P forming angles of 30 degrees with the horizontal. Now adjust the compasses to draw circles having a radius of one inch. With I as a center, draw the circle H P T R. With the same radius (one inch) draw the arcs with centers at A, B, C and D. Also draw the semi-circles with centers at L, F, M and E. Now draw the arcs as shown having centers at the centers of the small squares A L I E, L B F I, etc. To locate the centers of the six small circles within the circle H P T R, draw a circle with a radius of $\frac{11}{16}$ inch and having the center in I. The small circles have a radius of $\frac{5}{16}$ inch.

Inking. In inking this plate, the outlines of the squares of the various figures are inked only in *Figs.* 2 and *3*. In *Fig. 1* the only lines to be inked are those shown in **full** lines in *PLATE III.* First ink the star and then the square and diamonds. The cross hatching should be done *without* measuring the distance between the lines and without the aid of any cross hatching device as this is an exercise for practice. The lines should be about $\frac{1}{16}$ inch apart. After inking erase all construction lines.

In inking *Fig. 2* be careful not to run over lines. Each line should coincide with the pencil line. The student should

first ink the horizontal lines L, M and N and the vertical lines E, F and G. The short lines should have the same width but the border lines, A B, B C, C D and D A should be a little heavier.

Fig. 3 is drawn entirely with the 45-degree triangle. In inking the oblique lines make P I, R K, T M, etc., a light distinct line. The alternate lines O H, Q J, S L, etc., should be somewhat heavier. All of the lines which slope in the opposite direction are light. After inking *Fig. 3* all horizontal and vertical lines (except the border lines) should be erased. The border lines should be slightly heavier than the light oblique lines.

The only instrument used in inking *Fig. 4* is the compasses. In doing this exercise adjust the legs of the compasses so that the pen will always be perpendicular to the paper. If this is not done both nibs will not touch the paper and the line will be ragged. In inking the arcs, see that the pen stops *exactly* at the diagonals. The circle passing through T and the small inner circle should be dotted as shown in *PLATE III*. After inking the circles and arcs erase the construction lines that are without the outer circles but leave in *pencil* the diagonals inside the circle.

In *Fig. 5 draw all arcs first* and then draw the straight lines meeting these arcs. It is much easier to draw straight lines meeting arcs, or tangent to them, than to make the arcs tangent to straight lines. As this exercise is difficult, and in all mechanical and machine drawing arcs and tangents are frequently used we advise the beginner to draw this exercise several times. Leave all construction lines in pencil.

Fig. 6, like *Fig. 4*, is an exercise with compasses. If *Fig. 6* has been laid out accurately in pencil, the inked arcs will be tangent to each other and the finished exercise will have a good appearance. If, however, the distances were not accurately measured and the lines carefully drawn the inked arcs will not be tangent. The arcs whose centers are L, F, M and E and A, B, C and D should be heavier than the rest. The small circles may be drawn with the bow pen. After inking the arcs all construction lines should be erased.


ROMAN CLASSIC COLVMNS
ALBANI
FORTVNA VIRILIS
PANTHEON
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MECHANICAL DRAWING.

PART II.

GEOMETRICAL DEFINITIONS.

A **point** is used for marking position; it has neither length breadth nor thickness.

A **line** has length only; it is produced by the motion of a point.

A *straight line* or *right line* is one that has the same direction throughout. It is the shortest distance between any two of its points.

A *curved line* is one that is constantly changing in direction. It is sometimes called a curve.

A *broken line* is one made up of several straight lines.

Parallel lines are equally distant from each other at all points.

A *horizontal line* is one having the direction of a line drawn upon the surface of water that is at rest. It is a line parallel to the horizon.

A *vertical line* is one that lies in the direction of a thread suspended from its upper end and having a weight at the lower end. It is a line that is perpendicular to a horizontal plane.

Lines are *perpendicular* to each other, if when they cross, the four angles formed are equal. If they meet and form two equal angles they are perpendicular.

An *oblique line* is one that is neither vertical nor horizontal.

In Mechanical Drawing, lines drawn along the edge of the T square, when the head of the T square is resting against the left-hand edge of the board, are called horizontal lines. Those drawn at right angles or perpendicular to the edge of the T square are called vertical.

If two lines cut each other, they are called *intersecting lines*, and the point at which they cross is called the *point of intersection.*

ANGLES.

An **angle** is formed when two straight lines meet. An angle is often defined as being the difference in direction of two straight lines. The lines are called the *sides* and the point of meeting is called the *vertex*. The size of an angle depends upon the amount of divergence of the sides and is independent of the length of these lines.

RIGHT ANGLE. ACUTE ANGLE. OBTUSE ANGLE.

If one straight line meet another and the angles thus formed are equal they are **right angles.** When two lines are perpendicular to each other the angles formed are right angles.

An **acute angle** is less than a right angle.

An **obtuse angle** is greater than a right angle.

SURFACES.

A **surface** is produced by the motion of a line; it has two dimensions, — length and breadth.

A **plane figure** is a plane bounded on all sides by lines; the space included within these lines (if they are straight lines) is called a *polygon* or a *rectilinear figure.*

TRIANGLES.

A **triangle** is a figure enclosed by three straight lines. It is a polygon of three sides. The bounding lines are the *sides*, and the points of intersection of the sides are the *vertices*. The *angles* of a triangle are the angles formed by the sides.

A **right-angled** triangle, often called a *right* triangle, is one that has a right angle.

An **acute-angled** triangle is one that has all of its angles acute.

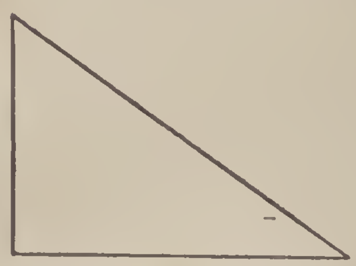
An **obtuse-angled** triangle is one that has an obtuse angle.

In an **equilateral** triangle all of the sides are equal.

If all of the *angles* of a triangle are equal, the figure is called an **equiangular** triangle.

A triangle is called **scalene**, when no two of its sides are equal.

In an **isosceles** triangle two of the sides are equal.


RIGHT ANGLED TRIANGLE.


ACUTE ANGLED TRIANGLE.


OBTUSE ANGLED TRIANGLE.

The *base* of a triangle is the lowest side ; however, any side may be taken as the base. In an isosceles triangle the side which is not one of the equal sides is usually considered the base.

The *altitude* of a triangle is the perpendicular drawn from the vertex to the base.


EQUILATERAL TRIANGLE.


ISOSCELES TRIANGLE.


SCALENE TRIANGLE.

QUADRILATERALS.

A **quadrilateral** is a plane figure bounded by four straight lines.

The *diagonal* of a quadrilateral is a straight line joining two opposite vertices.


QUADRILATERAL.


TRAPEZOID.


PARALLELOGRAM.

A **trapezium** is a quadrilateral, no two of whose sides are parallel.

A **trapezoid** is a quadrilateral having two sides parallel.

The *bases* of a trapezoid are its parallel sides. The *altitude* is the perpendicular distance between the bases.

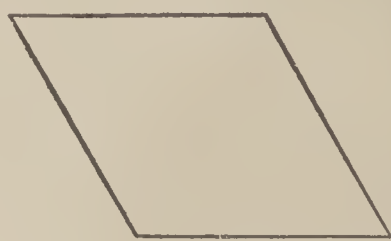
A **parallelogram** is a quadrilateral whose opposite sides are parallel.

The *altitude* of a parallelogram is the perpendicular distance between the bases which are the parallel sides.

There are four kinds of parallelograms:

RECTANGLE.

SQUARE.



RHOMBUS.

A **rectangle** is a parallelogram, all of whose angles are right angles. The opposite sides are equal.

A **square** is a rectangle, all of whose sides are equal.

A **rhombus** is a parallelogram which has four equal sides; but the angles are not right angles.

A **rhomboid** is a parallelogram whose adjacent sides are unequal; the angles are not right angles.

POLYGONS.

A **polygon** is a plane figure bounded by straight lines.

The boundary lines are called the *sides* and the sum of the sides is called the *perimeter*.

Polygons are classified according to the number of sides.

A **triangle** is a polygon of *three* sides.

A **quadrilateral** is a polygon of *four* sides.

A **pentagon** is a polygon of *five* sides.

A **hexagon** is a polygon of *six* sides.

A **heptagon** is a polygon of *seven* sides.

An **octagon** is a polygon of *eight* sides.

A **decagon** is a polygon of *ten* sides.

A **dodecagon** is a polygon of *twelve* sides.

An *equilateral* polygon is one all of whose sides are equal.

An *equiangular* polygon is one all of whose angles are equal.

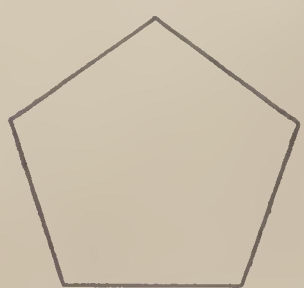
A *regular polygon* is one all of whose angles are equal and all of whose sides are equal.

CIRCLES.

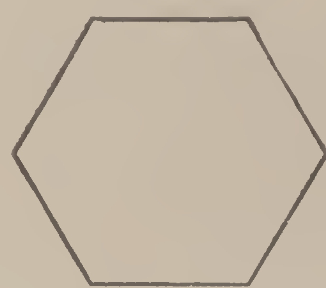
A **circle** is a plane figure bounded by a curved line, every point of which is equally distant from a point within called the center.

The curve which bounds the circle is called the **circumference** Any portion of the circumference is called an *arc.*

The **diameter** of a circle is a straight line drawn through the center and terminating in the circumference. A **radius** is a straight line joining the center with the circumference. It has a length equal to one half the diameter. All radii (plural of radius) are equal and all diameters are equal since a diameter equals two radii.



PENTAGON.



HEXAGON.

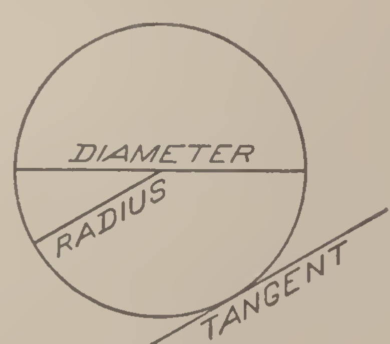
OCTAGON.

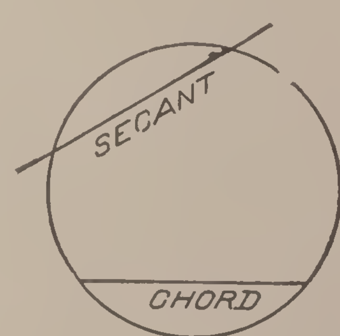
An arc equal to one-half the circumference is called a *semi-circumference*, and an arc equal to one-quarter of the circumference is called a *quadrant.* A quadrant may mean the sector, arc or angle.

A **chord** is a straight line joining the extremities of an arc. It is a line drawn across a circle that does not pass through the center.

A **secant** is a straight line which intersects the circumference in two points.

CIRCLE.



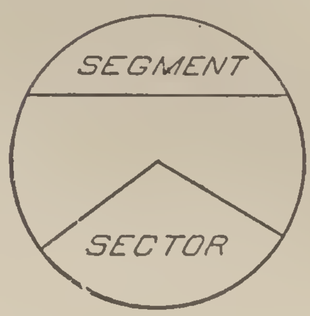


A **tangent** is a straight line which touches the circumference at only one point. It does not intersect the circumference. The point at which the tangent touches the circumference is called the *point of tangency* or *point of contact.*

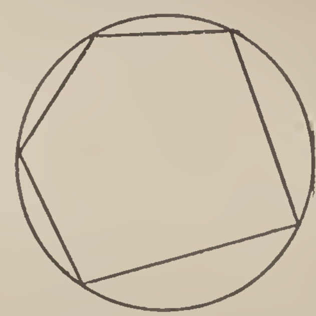
A **sector** of a circle is the portion or area included between an arc and two radii drawn to the extremities of the arc.

A **segment** of a circle is the area included between an arc and its chord.

Circles are **tangent** when the circumferences touch at only one point and are **concentric** when they have the same center.



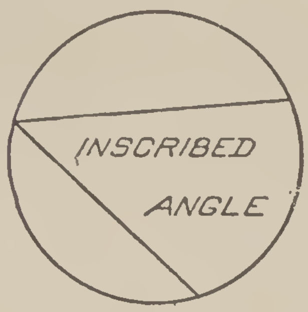
CONCENTRIC CIRCLES.

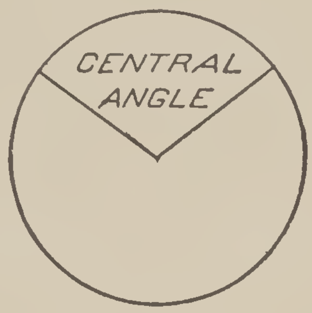


INSCRIBED POLYGON

An **inscribed angle** is an angle whose vertex lies in the circumference and whose sides are chords. It is measured by one-half the intercepted arc.

A **central angle** is an angle whose vertex is at the center of the circle and whose sides are radii.





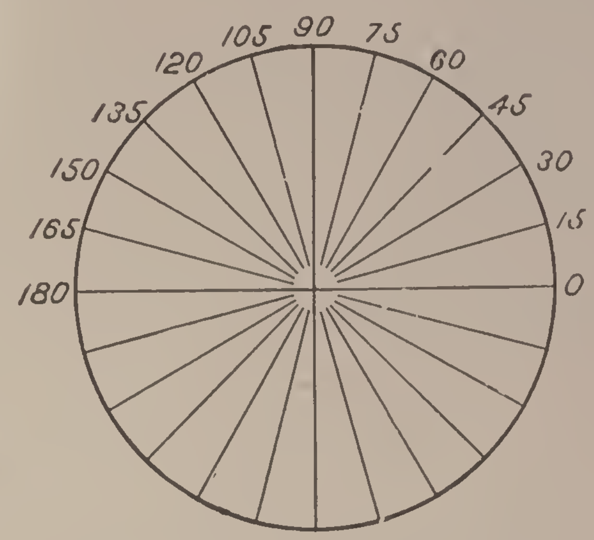
An **inscribed polygon** is one whose vertices lie in the circumference and whose sides are chords.

MEASUREMENT OF ANGLES.

To measure an angle describe an arc with the center at the vertex of the angle and having any convenient radius. The portion of the arc included between the sides of the angle is the measure of the angle. If the arc has a constant radius the greater the divergence of the sides, the longer will be the arc. If there are several arcs drawn with the same center, the intercepted arcs will have different lengths but they will all be the *same fraction* of the entire circumference.

In order that the size of an angle or arc may be stated with-

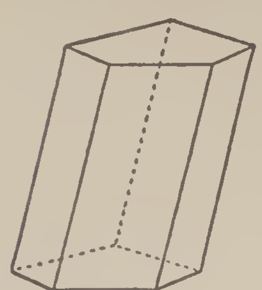
out saying that it is a certain fraction of a circumference, the circumference is divided into 360 equal parts called degrees. Thus we can say that an angle contains 45 degrees, which means that it is $\frac{45}{360} = \frac{1}{8}$ of a circumference. In order to obtain accurate measurements each degree is divided into 60 equal parts called *minutes* and each minute is divided into 60 equal parts called *seconds*. Angles and arcs are usually measured by means of an instrument called a protractor which has already been explained.



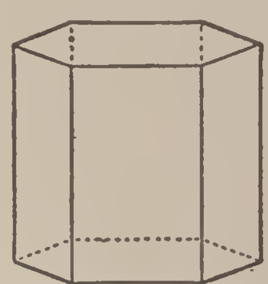
SOLIDS.

A **polyedron** is a solid bounded by planes. The bounding planes are called the *faces* and their intersections *edges*. The intersections of the edges are called *vertices*.

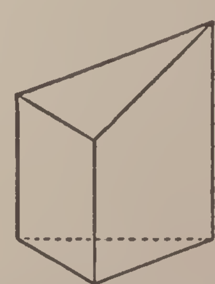
A polygon having four faces is called a **tetraedron**; one having six faces a **hexaedron**; of eight faces an **octaedron**; of twelve faces a **dodecaedron**, etc.



PRISM.



RIGHT PRISM.



TRUNCATED PRISM.

A **prism** is a polyedron, of which two opposite faces, called bases, are equal and parallel; the other faces, called lateral faces are parallelograms.

The area of the lateral faces is called the *lateral area.*

The *altitude* of a prism is the perpendicular distance between the bases.

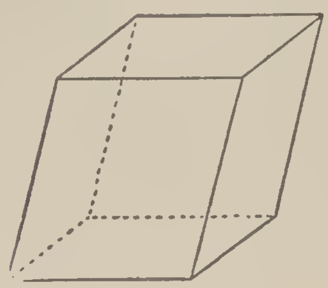
Prisms are *triangular*, *quadrangular*, etc., according to the shape of the base.

A **right** prism is one whose lateral edges are perpendicular to the bases.

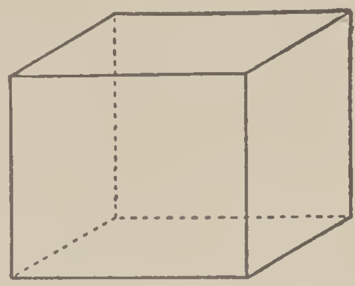
A **regular** prism is a right prism having regular polygons for bases.

A **parallelopiped** is a prism whose bases are parallelograms. If the edges are all perpendicular to the bases it is called a **right** parallelopiped.

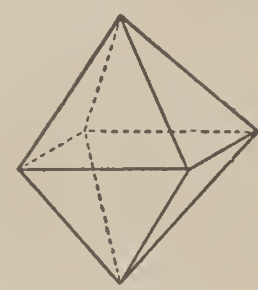
A **rectangular parallelopiped** is a right parallelopiped whose bases are rectangles ; all the faces are rectangles.



PARALLELOPIPED.



RECTANGULAR PARALLELOPIPED.



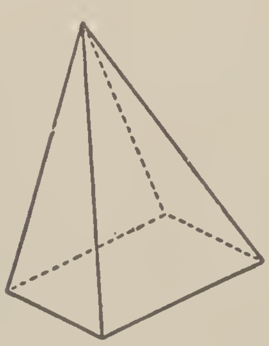
OCTAEDRON.

A **cube** is a rectangular parallelopiped all of whose faces are squares.

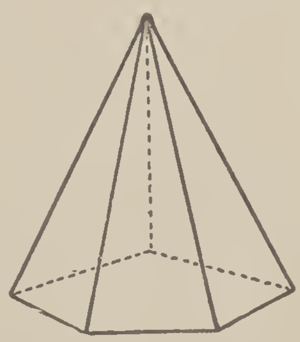
A **truncated prism** is the portion of a prism included between the base and a plane not parallel to the base.

PYRAMIDS.

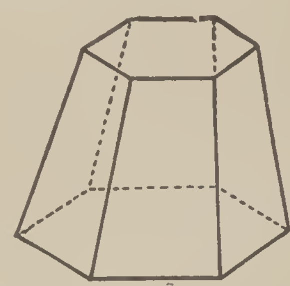
A **pyramid** is a polyedron one face of which is a polygon (called the base) and the other faces are triangles having a common vertex.



PYRAMID.



REGULAR PYRAMID.



FRUSTUM OF PYRAMID.

The vertices of the triangles form the *vertex* of the pyramid.

The *altitude* of the pyramid is the perpendicular distance from the vertex to the base.

A pyramid is called **triangular, quadrangular,** etc., according to the shape of the base.

A **regular pyramid** is one whose base is a regular polygon

and whose vertex lies in the perpendicular erected at the center of the base.

A **truncated pyramid** is the portion of a pyramid included between the base and a plane not parallel to the base.

A **frustum** of a pyramid is the solid included between the base and a plane parallel to the base.

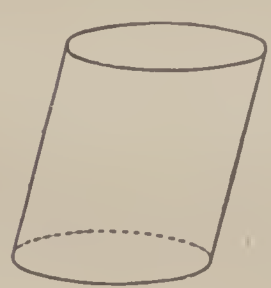
The *altitude* of a frustum of a pyramid is the perpendicular distance between the bases.

CYLINDERS.

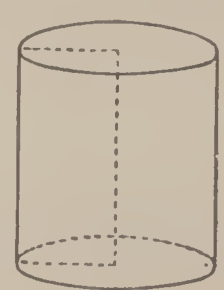
A **cylindrical surface** is a curved surface generated by the motion of a straight line which touches a curve and continues parallel to itself.

A **cylinder** is a solid bounded by a cylindrical surface and two parallel planes intersecting this surface.

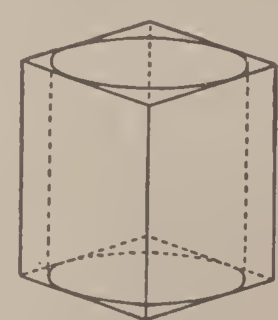
The parallel faces are called *bases.*



CYLINDER.



RIGHT CYLINDER.



INSCRIBED CYLINDER.

The *altitude* of a cylinder is the perpendicular distance between the bases.

A **circular cylinder** is a cylinder whose base is a circle.

A **right cylinder** or a *cylinder of revolution* is a cylinder generated by the revolution of a rectangle about one side as an axis.

A prism whose base is a regular polygon may be inscribed in or circumscribed about a circular cylinder.

The cylindrical area is call the *lateral area.* The *total area* is the area of the bases added to the lateral area.

CONES.

A **conical surface** is a curved surface generated by the motion of a straight line, one point of which is fixed and the end or ends of which move in a curve.

A **cone** is a solid bounded by a conical surface and a plane which cuts the conical surface.

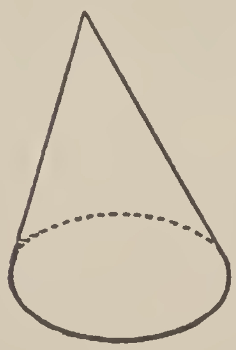
The plane is called the *base* and the curved surface the lateral area.

The *vertex* is the fixed point.

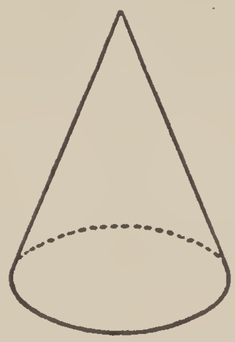
The *altitude* of a cone is the perpendicular distance from the vertex to the base.

An *element* of a cone is a straight line from the vertex to the perimeter of the base.

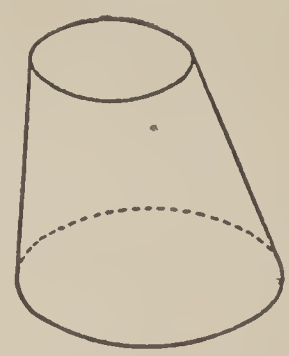
A **circular cone** is a cone whose base is a circle.



CONE.



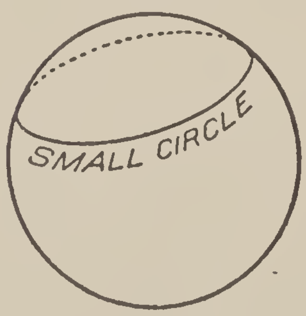
RIGHT CIRCULAR CONE.



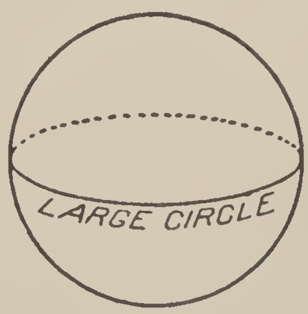
FRUSTUM OF CONE.

A **right circular cone** or **cone of revolution** is a cone whose axis is perpendicular to the base. It may be generated by the revolution of a right triangle about one of the perpendicular sides as an axis.

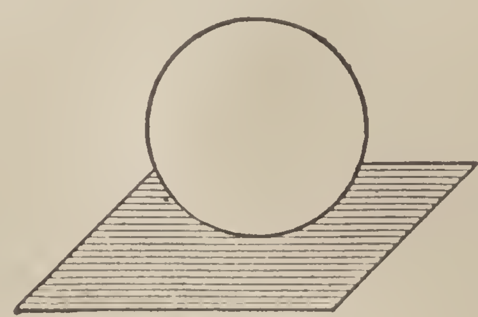
A **frustum** of a cone is the solid included between the base and a plane parallel to the base.



SPHERE.



SPHERE.



TANGENT PLANE.

The *altitude* of a frustum of a cone is the perpendicular distance between the bases.

SPHERES.

A **sphere** is a solid bounded by a curved surface, every point of which is equally distant from a point within called the center.

The *radius* of a sphere is a straight line drawn from the

center to the surface. The *diameter* is a straight line drawn through the center and having its extremities in the surface.

A sphere may be generated by the revolution of a semi-circle about its diameter as an axis.

An *inscribed polyedron* is a polyedron whose vertices lie in the surface of the sphere.

An *circumscribed polyedron* is a polyedron whose faces are tangent to a sphere.

A *great circle* is the intersection of the spherical surface and a plane passing through the center of a sphere.

A *small circle* is the intersection of the spherical surface and a plane which does not pass through the center.

A sphere is *tangent* to a plane when the plane touches the surface in only one point. A plane perpendicular to the extremity of a radius is tangent to the sphere.

CONIC SECTIONS.

If a plane intersects a cone the geometrical figures thus formed are called conic sections. A plane perpendicular to the base and passing through the vertex of a right circular cone forms an isosceles triangle. If the plane is parallel to the base the intersection of the plane and conical surface will be the circumference of a circle.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

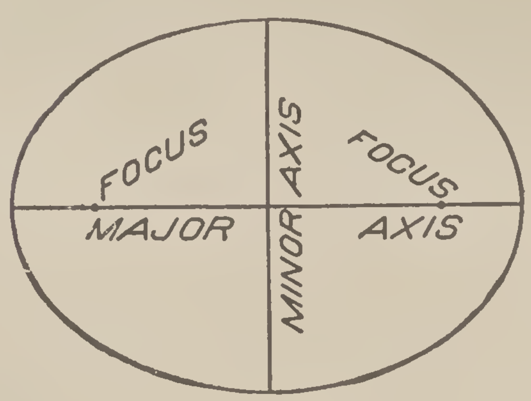
Ellipse. The ellipse is a curve formed by the intersection of a plane and a cone, the plane being oblique to the axis but not cutting the base. If a plane is passed through a cone as shown in Fig. 1 or through a cylinder as shown in Fig 2, the curve of intersection will be an ellipse. An ellipse may be defined as being *a curve generated by a point moving in a plane, the sum of the distances of the point to two fixed points being always constant.*

The two fixed points are called the **foci** and lie on the

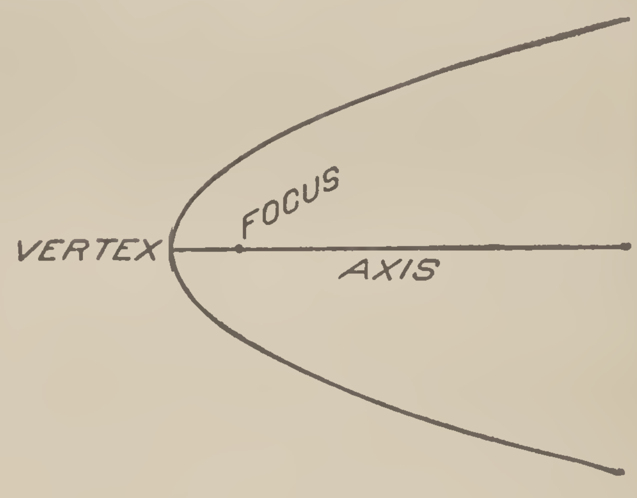
longest line that can be drawn in the ellipse. One of these points is called a *focus.*

The longest line that can be drawn in an ellipse is called the **major axis** and the shortest line, passing through the center, is called the **minor axis.** The minor axis is perpendicular to the middle point of the major axis and the point of intersection is called the center

An ellipse may be constructed if the major and minor axes are given or if the foci and one axis are known.



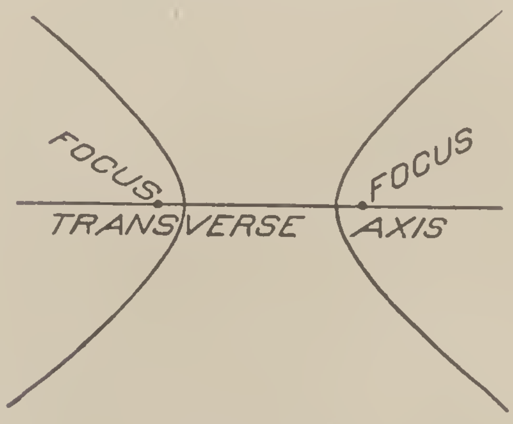
ELLIPSE.



PARABOLA.

Parabola. The parabola is a curve formed by the intersection of a cone and a plane parallel to an element as shown in Fig. 3. The curve is not a closed curve. The branches approach parallelism.

A parabola may be defined as being *a curve every point of which is equally distant from a line and a point.*



HYPERBOLA.

The point is called the **focus** and the given line the **directrix.** The line perpendicular to the directrix and passing through the focus is the **axis.** The intersection of the axis and the curve is the **vertex.**

Hyperbola. This curve is formed by the intersection of a plane and a cone, the plane being parallel to the axis of the cone as shown in Fig. 4. Like the parabola, the curve is not a closed curve; the branches constantly diverge.

An hyperbola is defined as being *a plane curve such that the difference of the distances from any point in the curve to two fixed points is equal to a given distance.*

The two fixed points are the **foci** and the line passing through them is the **transverse axis.**

Rectangular Hyperbola. The form of hyperbola most used in Mechanical Engineering is called the rectangular hyperbola because it is drawn with reference to rectangular co-ordinates. This curve is constructed as follows: In Fig. 5, O X and O Y are the two co-ordinates drawn at right angles to each other. These lines are also called axes or asymptotes. Assume A to be a known point on the curve. In drawing this curve for the theoretical indicator card, this point A is the point of cut-off.

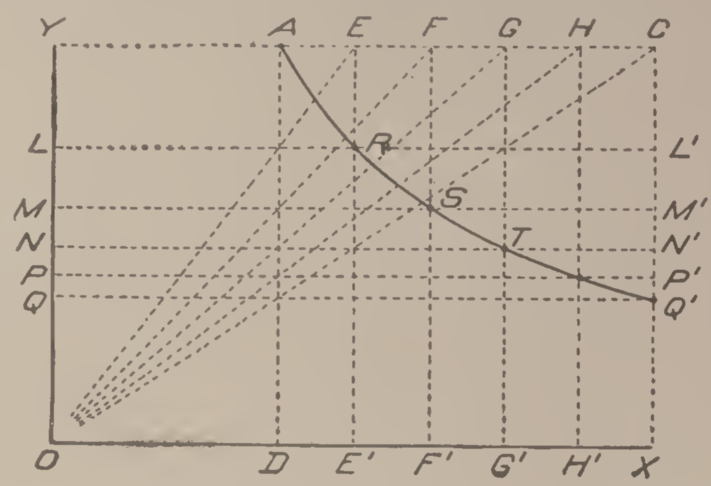


Fig. 5.

Draw A C parallel to O X and A D perpendicular to O X. Now mark off any convenient points on A C such as E, F, G, and H; and through these points draw EE′, FF′, GG′, and HH′ perpendicular to O X. Connect E, F, G, H and C with O. Through the points of intersection of the oblique lines and the vertical line A D draw the horizontal lines LL′, MM′, NN′, PP′ and QQ′. The first point on the curve is the assumed point A, the second point is R, the intersection of LL′ and EE′. The third is the intersection S of MM′ and FF′; the fourth is the intersection T of NN′ and GG′. The other points are found in the same way.

In this curve the products of the co-ordinates of all points are equal. Thus $LR \times RE' = MS \times SF' = NT \times TG'$.

ODONTOIDAL CURVES.

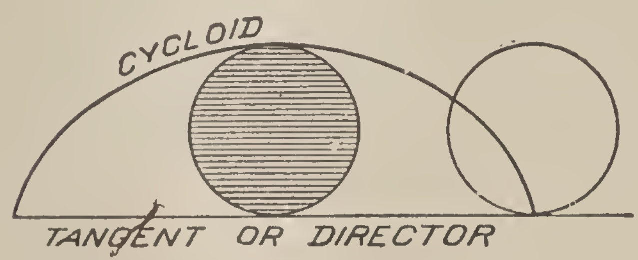
The outlines of the teeth of gears must be drawn accurately because the smoothness of running depends upon the shape of the teeth. The two classes of curves generally employed in drawing gear teeth are the cycloidal and involute.

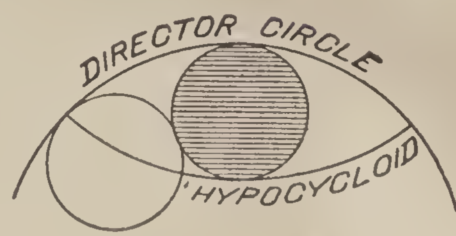
Cycloid. The cycloid is a curve generated by a point on the circumference of a circle which rolls on a straight line tangent to the circle.

The rolling circle is called the *describing* or *generating circle*

and the point, the *describing* or *generating point.* The tangent along which the circle rolls is called the *director.*

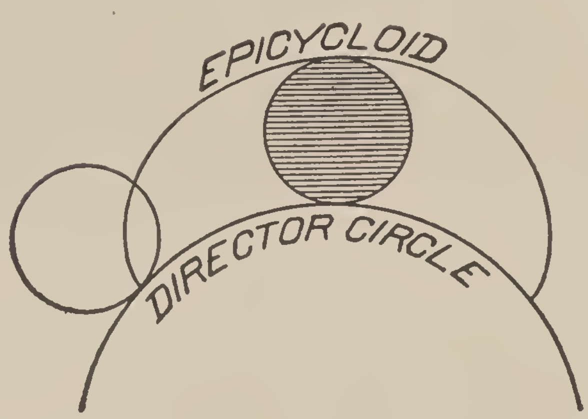
In order that the curve may be a true cycloid the circle must roll without any slipping.

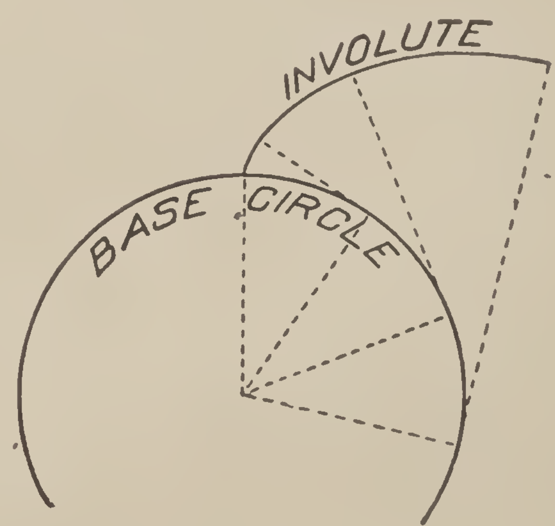




Epicycloid. If the generating circle rolls upon the *outside* of an arc or circle, called the *director circle*, the curve thus generated is called an epicycloid. The method of drawing this curve is the same as that for the cycloid.

Hypocycloid. In case the generating circle rolls upon the inside of an arc or circle, the curve thus generated is called the hypocycloid. The circle upon which the generating circle rolls is





called the *director circle.* If the generating circle has a diameter equal to the radius of the director circle the hypocycloid becomes a straight line.

Involute. If a thread or fine wire is wound around a cylinder or circle and then unwound, the end will describe a curve called an involute. The involute may be defined as being *a curve generated by a point in a tangent rolling on a circle known as the base circle.*

The construction of the ellipse, parabola, hyperbola and odontoidal curves will be taken up in detail with the plates.

PLATE IV.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE IV* should be laid out in the same manner as were those for *PLATE I.* There are to be six figures on this plate and to facilitate the laying out of the work, the following lines should be drawn: measure off $2\frac{1}{4}$ inches on both sides of the vertical center line and through these points draw vertical lines as shown in dot and dash lines on *PLATE IV.* In these six spaces the six figures are to be drawn, the student placing them in the centers of the spaces so that they will present a good appearance. In locating the figures, they should be placed a little above the center so that there will be sufficient space below to number the problem.

The figures of the problems should first be drawn lightly in pencil and after the entire plate is completed the lines should be inked. In pencilling, all intersections must be formed with great care as the accuracy of the results depends upon the pencilling. Keep the pencil points in good order at all times and draw lines *exactly* through intersections.

GEOMETRICAL PROBLEMS.

The following problems are of great importance to the mechanical draughtsman. The student should solve them with care; he should not do them blindly, but should understand them so that he can apply the principles in later work.

PROBLEM I. **To Bisect a Given Straight Line.**

Draw the horizontal straight line A C about 3 inches long. With the extremity A as a center and any convenient radius (about 2 inches) describe arcs above and below the line A C. With the other extremity C as a center and with the same radius draw short arcs above and below A C intersecting the first arcs at D and E. The radius of these arcs must be greater than one-half the length of the line in order that they may intersect. Now draw the straight line D E passing through the intersections D and E. This line cuts the line A C at F which is the middle point.

$$A F = F C$$

Proof. Since the points D and E are equally distant from A and C a straight line drawn through them is perpendicular to A C at its middle point F.

PROBLEM 2. **To Construct an Angle Equal to a Given Angle.**

Draw the line O C about 2 inches long and the line O A of about the same length. The angle formed by these lines may be any convenient size (about 45 degrees is suitable). This angle A O C is the given angle.

Now draw F G a horizontal line about $2\frac{1}{4}$ inches long and let F the left-hand extremity be the vertex of the angle to be constructed.

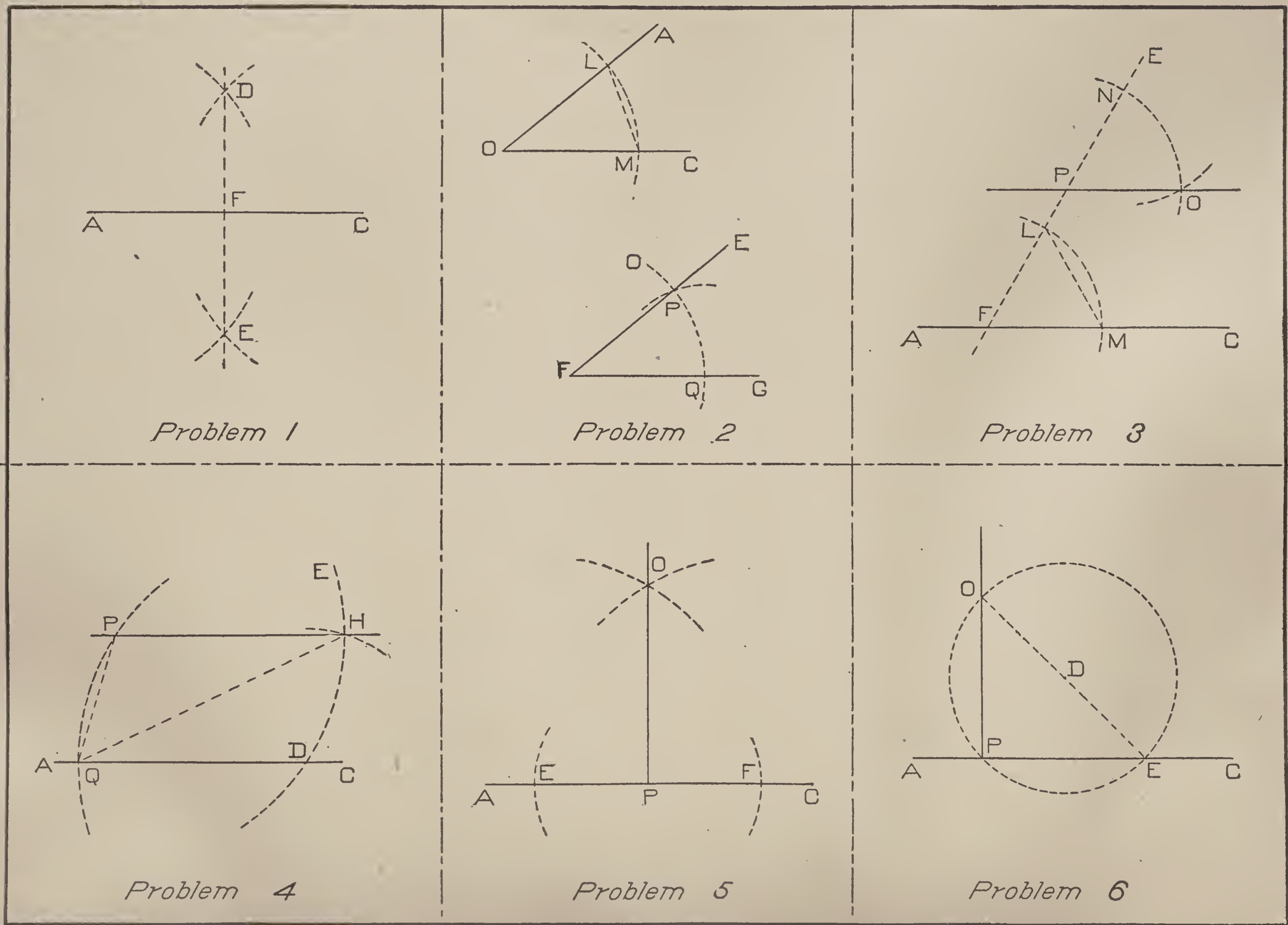
With O as a center and any convenient radius (about $1\frac{1}{2}$ inches) describe the arc L M cutting both O A and O C. With F as a center and the same radius draw the indefinite arc O Q. Now set the compass so that the distance between the pencil and the needle point is equal to the chord L M. With Q as a center and a radius equal to L M draw an arc cutting the arc O Q at P. Through F and P draw the straight line F E. The angle E F G is the required angle since it is equal to A O C.

Proof. Since the chords of the arcs L M and P Q are equal the arcs are equal. The angles are equal because with equal radii equal arcs are intercepted by equal angles.

PROBLEM 3. **To Draw Through a Given Point a Line Parallel to a Given Line.**

First Method. Draw the horizontal straight line A C about $3\frac{1}{2}$ inches long and assume the point P about $1\frac{1}{2}$ inches above A C. Through the point P draw an oblique line F E forming any convenient angle with A C. (Make the angle about 60 degrees). Now construct an angle equal to P F C having the vertex at P and one side the line E P. (See problem 2). This may be done as follows: With F as a center and any convenient radius, describe the arc L M. With the same radius draw the indefinite arc N O using P as the center. With N as a center and a radius equal to the chord L M, draw an arc cutting the arc N O at O. Through the points P and O draw a straight line which will be parallel to A C.

PLATE IV



Problem 1

Problem 2

Problem 3

Problem 4

Problem 5

Problem 6

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Proof. If two straight lines are cut by a third making the corresponding angles equal, the lines are parallel.

PROBLEM 4. **To Draw Through a Given Point a Line Parallel to a Given Line.**

Second Method. Draw the straight line A C about $3\frac{1}{4}$ inches long and assume the point P about $1\frac{1}{2}$ inches above A C. With P as a center and any convenient radius (about $2\frac{1}{2}$ inches) draw the indefinite arc E D cutting the line A C. Now with the same radius and with D as a center, draw an arc P Q. Set the compass so that the distance between the needle point and the pencil is equal to the chord P Q. With D as a center and a radius equal to P Q, describe an arc cutting the arc E D at H. A line drawn through P and H will be parallel to A C.

Proof. Draw the line Q H. Since the arcs P Q and H D are equal and have the same radii, the angles P H Q and H Q D are equal. Two lines are parallel if the alternate interior angles are equal.

PROBLEM 5. **To Draw a Perpendicular to a Line from a Point in the Line.**

First Method. When the point is near the middle of the line.

Draw the horizontal line A C about $3\frac{1}{2}$ inches long and assume the point P near the middle of the line. With P as a center and any convenient radius (about $1\frac{1}{4}$ inches) draw two arcs cutting the line A C at E and F. Now with E and F as centers and any convenient radius (about $2\frac{1}{2}$ inches) describe arcs intersecting at O. The line O P will be perpendicular to A C at P.

Proof. The points P and O are equally distant from E and F. Hence a line drawn through them is perpendicular to the middle point of E F which is P.

PROBLEM 6. **To Draw a Perpendicular to a Line from a Point in the Line.**

Second Method. When the point is near the end of the line.

Draw the line A C about $3\frac{1}{2}$ inches long. Assume the given point P to be about $\frac{3}{4}$ inch from the end A. With any point D as a center and a radius equal to D P, describe an arc, cutting A C at E. Through E and D draw the diameter E O. A line from O to P is perpendicular to A C at P.

Proof. The angle O P E is inscribed in a semi-circle; hence it is a right angle, and the sides O P and P E are perpendicular to each other.

After completing these figures draw pencil lines for **the** lettering. The words "*PLATE IV*" and the date and name should be placed in the border, as in preceding plates. To letter the words "Problem 1," "Problem 2," etc., draw horizontal lines $\frac{1}{4}$ inch above the horizontal center line and the lower border line. Draw another line $\frac{3}{16}$ inch above, to limit the height of the P, *b* and *l*. Draw a third line $\frac{1}{8}$ inch above the lower line as a guide line for the tops of the small letters.

Inking. In inking *PLATE IV* the figures should be inked first. The line A C of Problem 1 should be a full line as it is the given line; the arcs and line D E, being construction lines should be dotted. In Problem 2, the sides of the angles should be full lines. Make the chord L M and the arcs dotted, since as before, they are construction lines.

In Problem 3, the line A C is the given line and P O is the line drawn parallel to it. As E F and the arcs do not form a part of the problem but are merely construction lines, drawn as an aid in locating P O, they should be dotted. In Problems 4, 5 and 6, the assumed lines and those found by means of the construction lines should be full lines. The arcs and construction lines should be dotted. In Problem 6, the entire circumference need not be inked, only that part is necessary that is used in the problem. The inked arc should however be of sufficient length to pass through the points O, P and E.

After inking the figures, the border lines should be inked with a heavy line as before. Also, the words "*PLATE IV*" and the date and the student's name. Under each problem the words "Problem 1," "Problem 2," etc., should be inked; lower case letters being used as shown.

PLATE V.

Pencilling. In laying out the border lines and centre lines follow the directions given for *PLATE IV.* The dot and dash lines should be drawn in the same manner as there are to be six problems on this plate.

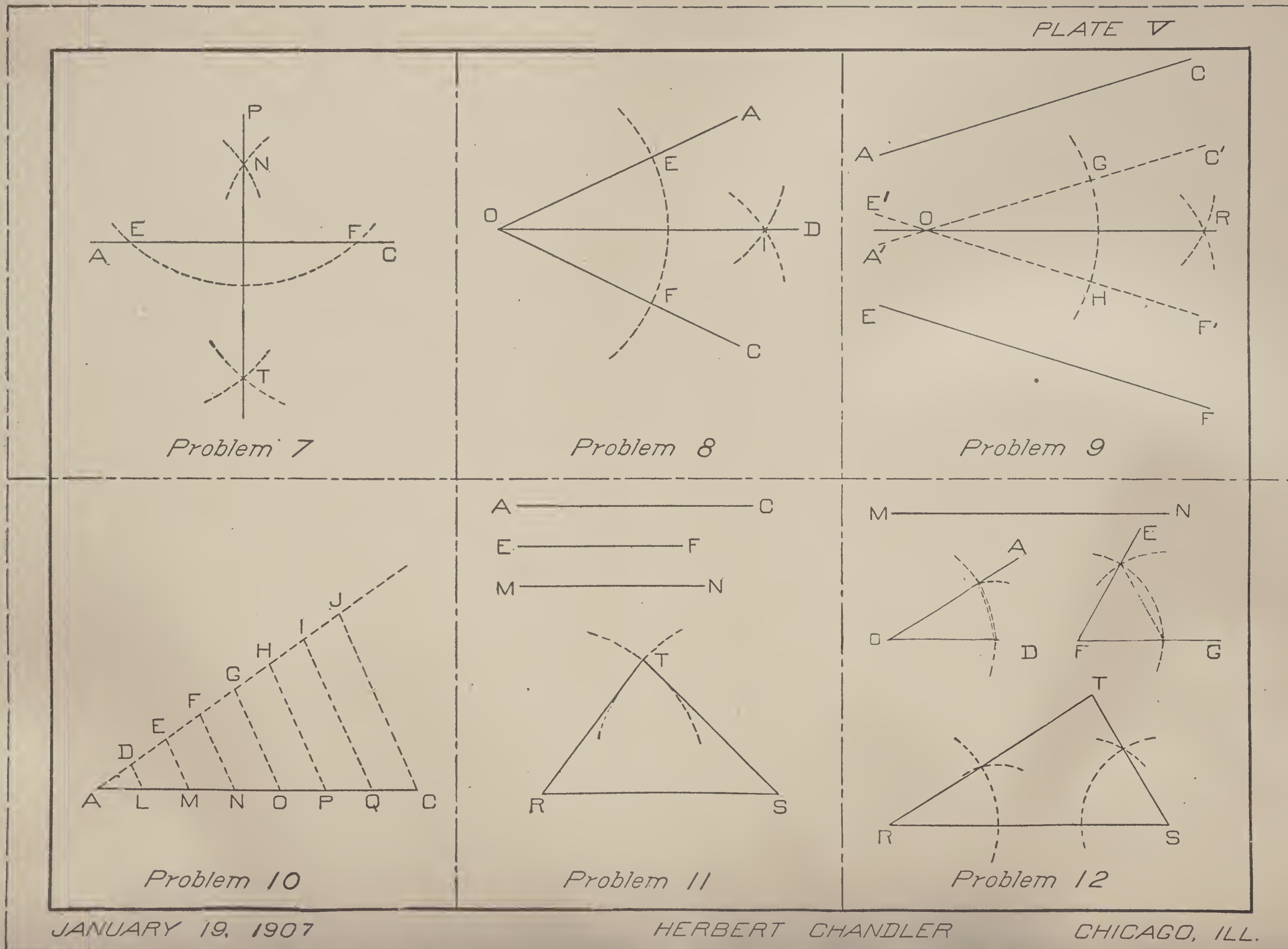
PLATE V
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A
C
E
F
M
N
T
R
S
Problem 11
M
N
A
E
O
D
F
G
T
R
S
Problem 12
JANUARY 19, 1907
HERBERT CHANDLER
CHICAGO, ILL.

PROBLEM 7. **To Draw a Perpendicular to a Line from a Point without the Line.**

Draw the horizontal straight line A C about $3\frac{1}{4}$ inches long. Assume the point P about $1\frac{1}{2}$ inches above the line. With P as a center and any convenient radius (about 2 inches) describe an arc cutting A C at E and F. The radius of this arc must always be such that it will cut A C in two points; the nearer the points E and F are to A and C, the greater will be the accuracy of the work. Now with E and F as centers and any convenient radius (about $2\frac{1}{4}$ inches) draw the arcs intersecting below A C at T. A line through the points P and T will be perpendicular to A C.

In case there is not room below A C to draw the arcs, they may be drawn intersecting above the line as shown at N. Whenever convenient, draw the arcs below A C for greater accuracy.

Proof. Since P and T are equally distant from E and F, the line P T is perpendicular to A C.

PROBLEM 8. **To Bisect a Given Angle.**

First Method. When the sides intersect.

Draw the lines O C and O A forming any angle (from 45 to 60 degrees). These lines should be about 3 inches long. With O as a center and any convenient radius (about 2 inches) draw an arc intersecting the sides of the angle at E and F. With E and F as centers and a radius of $1\frac{1}{2}$ or $1\frac{3}{4}$ inches, describe short arcs intersecting at I. A line O D, drawn through the points O and I, bisects the angle.

In solving this problem the arc E F should not be too near the vertex if accuracy is desired.

Proof. The central angles A O D and D O C are equal because the arc E F is bisected by the line O D. The point I is equally distant from E and F.

PROBLEM 9. **To Bisect a Given Angle.**

Second Method. When the lines do not intersect.

Draw the lines A C and E F about 4 inches long and in the positions as shown on *PLATE V.* Draw A′ C′ and E′ F′ parallel to A C and E F and at such equal distances from them that they will intersect at O. Now bisect the angle C′ O F′ by

the method of Problem 8. Draw the arc G H and with G and H as centers draw the arcs intersecting at R. The line O R bisects the angle.

Proof. Since $A' C'$ is parallel to A C and $E' F'$ parallel to E F, the angle $C' O F'$ is equal to the angle formed by the lines A C and E F. Hence as O R bisects angle $C' O F'$ it also bisects the angle formed by the lines A C and E F.

PROBLEM 10. **To Divide a Given Line into any Number of Equal Parts.**

Let A C, about $3\frac{3}{4}$ inches long, be the given line. Let us divide it into 7 equal parts. Draw the line A J at least 4 inches long, forming any convenient angle with A C. On A J lay off, by means of the dividers or scale, points D, E, F, G, etc., each $\frac{1}{2}$ inch apart. If dividers are used the spaces need not be exactly $\frac{1}{2}$ inch. Draw the line J C and through the points D, E, F, G, etc., draw lines parallel to J C. These parallels will divide the line A C into 7 equal parts.

Proof. If a series of parallel lines, cutting two straight lines, intercept equal distances on one of these lines, they also intercept equal distances on the other.

PROBLEM 11. **To Construct a Triangle having given the Three Sides.**

Draw the three sides as follows:

A C, $2\frac{3}{4}$ inches long.
E F, $1\frac{15}{16}$ inches long.
M N, $2\frac{3}{16}$ inches long.

Draw R S equal in length to A C. With R as a center and a radius equal to E F describe an arc. With S as a center and a radius equal to M N draw an arc cutting the arc previously drawn, at T. Connect T with R and S to form the triangle.

PROBLEM 12. **To Construct a Triangle having given One Side and the Two Adjacent Angles.**

Draw the line M N $3\frac{1}{4}$ inches long and draw two angles A O D and E F G. Make the angle A O D about 30 degrees and E F G about 60 degrees.

Draw R S equal in length to M N and at R construct an

angle equal to A O D. At S construct an angle equal to E F G by the method used in Problem 2. *PLATE V* shows the necessary arcs. Produce the sides of the angles thus constructed until they meet at T. The triangle R T S will be the required triangle.

After drawing these six figures in pencil, draw the pencil lines for the lettering. The lines for the words "*PLATE V*," date and name, should be pencilled as explained on page 20. The words "Problem 7," "Problem 8," etc., are lettered as for *PLATE IV*.

Inking. In inking *PLATE V*, the same principles should be followed as stated with *PLATE IV*. The student should apply these principles and not make certain lines dotted just because they are shown dotted in *PLATE V*.

After inking the figures, the border lines should be inked and the lettering inked as already explained in connection with previous plates.

PLATE VI.

Pencilling. Lay out this plate in the same manner as the two preceding plates.

PROBLEM 13. **To describe an Arc or Circumference through Three Given Points not in the same straight line.**

Locate the three points A, B and C. Let the distance between A and B be about 2 inches and the distance between A and C be about $2\frac{1}{4}$ inches. Connect A and B and A and C. Erect perpendiculars to the middle points of A B and A C. This may be done as explained with Problem 1. With A and B as centers and a radius of about $1\frac{1}{2}$ inches, describe the arcs intersecting at I and J. With A and C as centers and with a radius of about $1\frac{3}{4}$ inches draw the arcs, intersecting at E and F. Now draw light pencil lines connecting the intersections I and J and E and F. These lines will intersect at O.

With O as a center and a radius equal to the distance O A, describe the circumference passing through A, B and C.

Proof. The point O is equally distant from A, B and C, since it lies in the perpendiculars to the middle points of A B and

A C. Hence the circumference will pass through A, B and C.

PROBLEM 14. **To inscribe a Circle in a given Triangle.**

Draw the triangle L M N of any convenient size. M N may be made $3\frac{1}{4}$ inches, L M, $2\frac{3}{4}$ inches, and L N, $3\frac{1}{2}$ inches. Bisect the angles M L N and L M N. The bisectors M I and L J may be drawn by the method used in Problem 8. Describe the arcs A C and E F, having centers at L and M respectively. The arcs intersecting at I and J are drawn as already explained. The bisectors of the angles intersect at O, which is the center of the inscribed circle. The radius of the circle is equal to the perpendicular distance from O to one of the sides.

Proof. The point of intersection of the bisectors of the angles of a triangle is equally distant from the sides.

PROBLEM 15. **To inscribe a Regular Pentagon in a given Circle.**

With O as a center and a radius of about $1\frac{1}{2}$ inches, describe the given circle. With the T square and triangles draw the center lines A C and E F. These lines should be perpendicular to each other and pass through O. Bisect one of the radii, such as O C, and with this point H as a center and a radius H E, describe the arc E P. This arc cuts the diameter A C at P. With E as a center and a radius E P, draw arcs cutting the circumference at L and Q. With the same radius and a center at L, draw the arc, cutting the circumference at M. To find the point N, use either M or Q as a center and the distance E P as a radius.

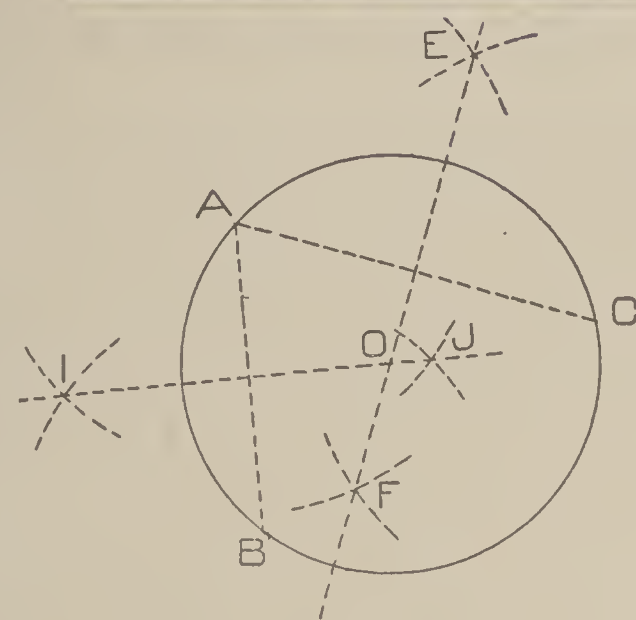
The pentagon is completed by drawing the chords E L, L M, M N, N Q and Q E.

PROBLEM 16. **To inscribe a Regular Hexagon in a given Circle.**

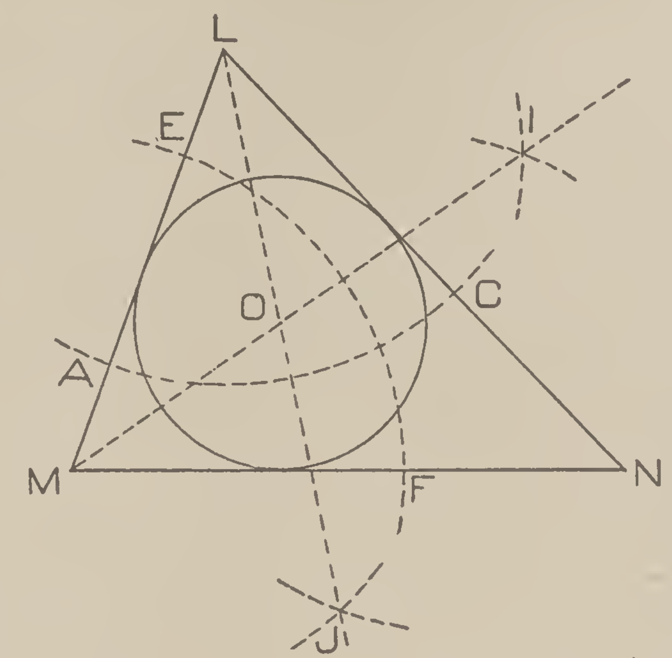
With O as a center and a radius of $1\frac{3}{8}$ inches draw the given circle. With the T square draw the diameter A D. With D as a center, and a radius equal to O D, describe arcs cutting the circumference at C and E. Now with C and E as centers and the same radius, draw the arcs, cutting the circumference at B and F. Draw the hexagon by joining the points thus formed.

To inscribe a regular hexagon in a circle mark off chords equal in length to the radius.

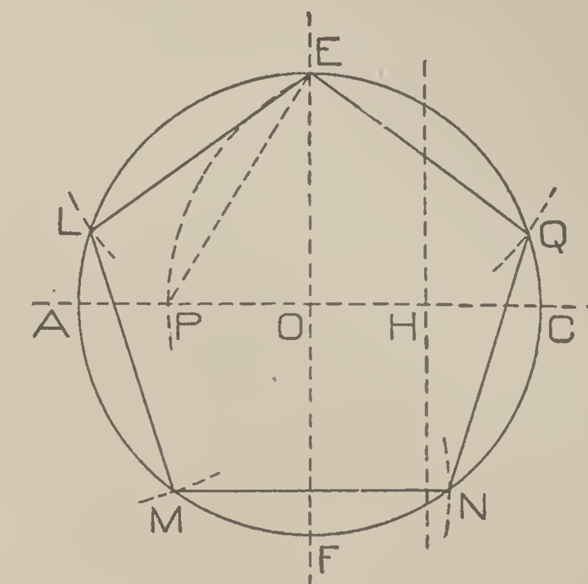
PLATE VI



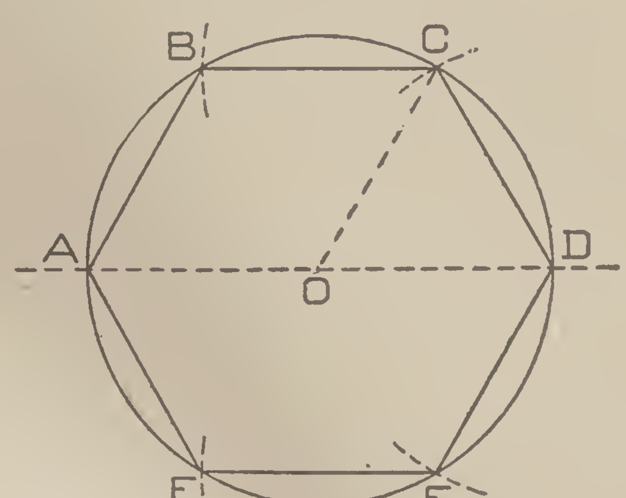
Problem 13



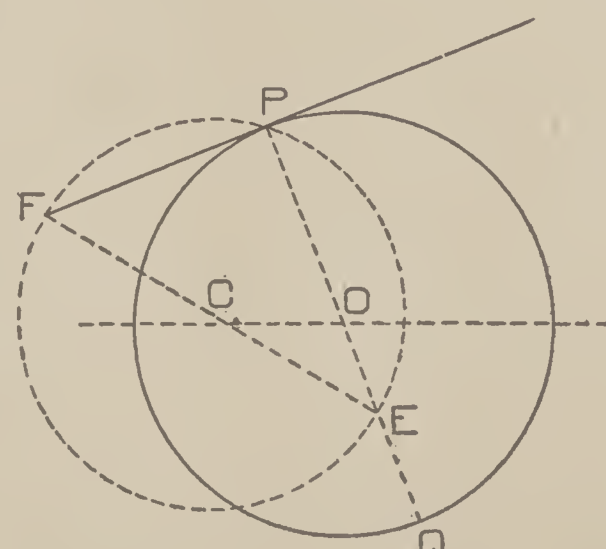
Problem 14



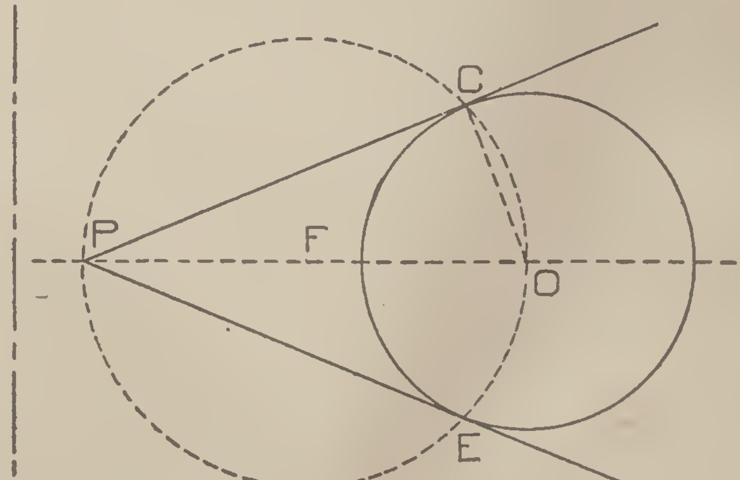
Problem 15



Problem 16



Problem 17



Problem 18

JANUARY 29. 1907 HERBERT CHANDLER CHICAGO, ILL.

To inscribe an equilateral triangle in a circle the same method may be used. The triangle is formed by joining the opposite vertices of the hexagon.

Proof. The triangle O C D is an equilateral triangle by construction. Then the angle C O D is one-third of two right angles and one-sixth of four right angles. Hence arc C D is one-sixth of the circumference and the chord is a side of a regular hexagon.

PROBLEM 17. **To draw a line Tangent to a Circle at a given point on the circumference.**

With O as a center and a radius of about $1\frac{1}{4}$ inches draw the given circle. Assume some point P on the circumference Join the point P with the center O and through P draw a line F P perpendicular to P O. This may be done in any one of several methods. Since P is the extremity of O P the method given in Problem 6 of *PLATE IV*, may be used.

Produce P O to Q. With any center C, and a radius C P draw an arc or circumference passing through P. Draw E F a diameter of the circle whose center is C and through F and P draw the tangent.

Proof. A line perpendicular to a radius at its extremity is tangent to the circle.

PROBLEM 18. **To draw a line Tangent to a Circle from a point outside the circle.**

With O as a center and a radius of about 1 inch draw the given circle. Assume P some point outside of the circle about $2\frac{1}{2}$ inches from the center of the circle. Draw a straight line passing through P and O. Bisect P O and with the middle point F as a center describe the circle passing through P and O. Draw a line through P and the intersection of the two circumferences C. The line P C is tangent to the given circle. Similarly P E is tangent to the circle.

Proof. The angle P C O is inscribed in a semi-circle and hence is a right angle. Since P C O is a right angle P C is perpendicular to C O. The perpendicular to a radius at its extremity is tangent to the circumference.

Inking. In inking *PLATE VI* the same method should be

followed as in previous plates. The name and address should be lettered in inclined Gothic capitals as before.

PLATE VII.

Pencilling. *PLATE VII* should be laid out in the same manner as previous plates. Six problems on the ellipse, spiral, parabola and hyperbola are to be constructed in the six spaces.

PROBLEM 19. **To draw an Ellipse when the Axes are given.**

Draw the lines L M and C D about $3\frac{1}{4}$ and $2\frac{1}{4}$ inches long respectively. Let C D be perpendicular to M N at its middle point P. Make C P = P D. These two lines are the axes. With C as a center and a radius equal to one-half the major axis or equal to L P, draw the arc, cutting the major axis at E and F. These two points are the foci. Now mark off any convenient distances on P M, such as A, B and G.

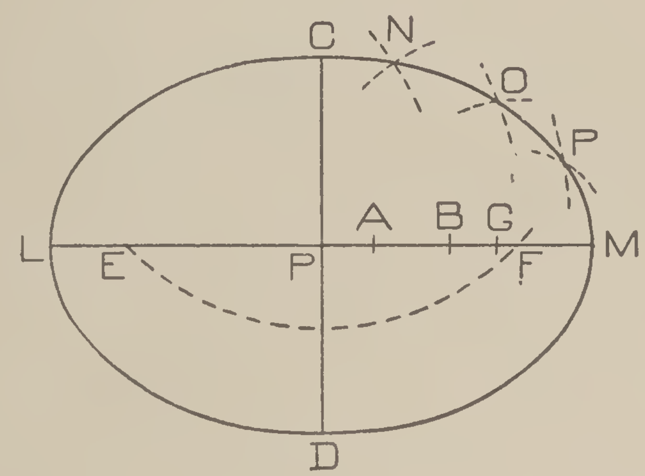
With E as a center and a radius equal to L A, draw arcs above and below L M. With F as a center, and a radius equal to A M describe short arcs cutting those already drawn as shown at N. With E as a center and a radius equal to L B draw arcs above and below L M as before. With F as a center and a radius equal to B M, draw arcs intersecting those already drawn as shown at O. The point P and others are found by repeating the process. The student is advised to find at least 12 points on the curve — 6 above and 6 below L M. These 12 points with L, C, M and D will enable the student to draw the curve.

After locating these points, a free hand curve passing through them should be sketched.

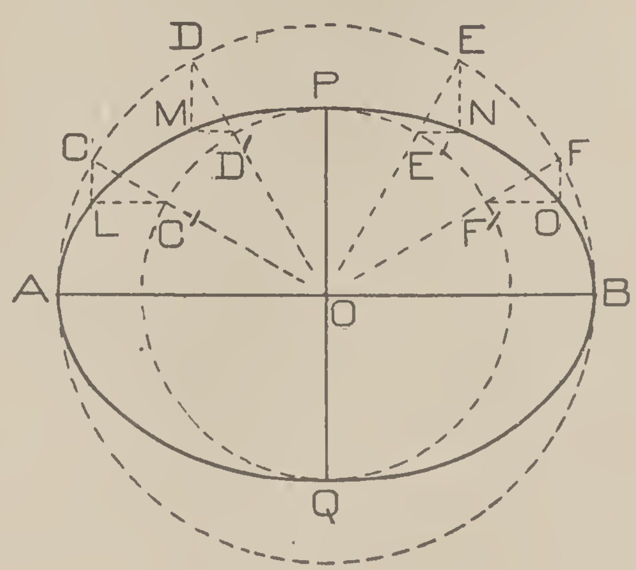
PROBLEM 20. **To draw an Ellipse when the two Axes are given.**

Second Method. Draw the two axes A B and P Q in the same manner as for Problem 19. With O as a center and a radius equal to one-half the major axis, describe the circumference A C D E F B. Similarly with the same center and a radius equal to one-half the minor axis, describe a circle. Draw any radii such as O C, O D, O E, O F, etc., cutting both circumferences. These radii may be drawn with the 60 and 45 degree triangles. At the

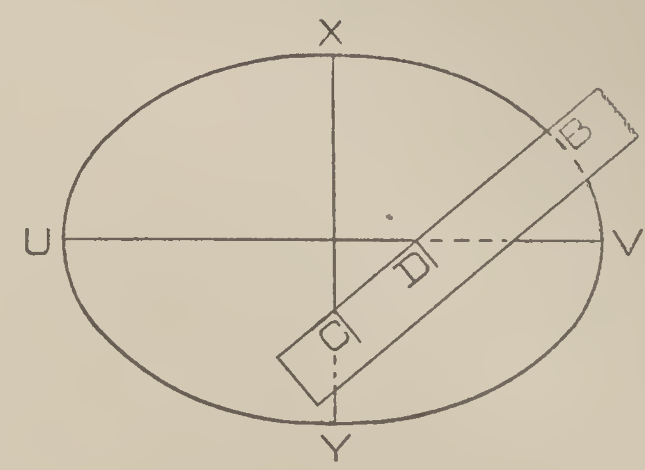
PLATE XII



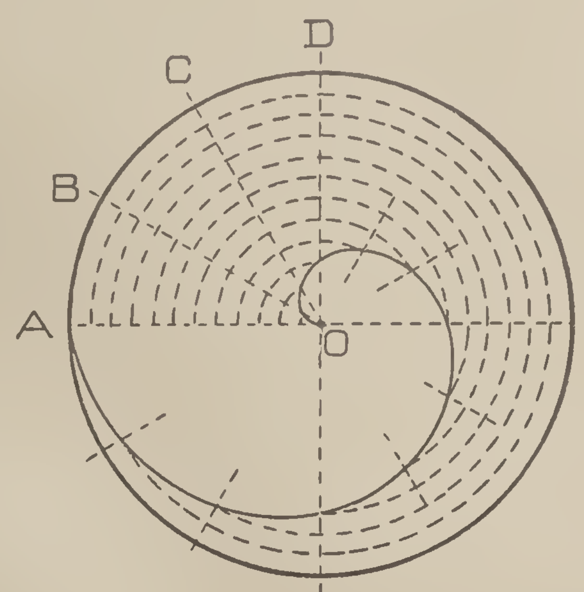
Problem 19



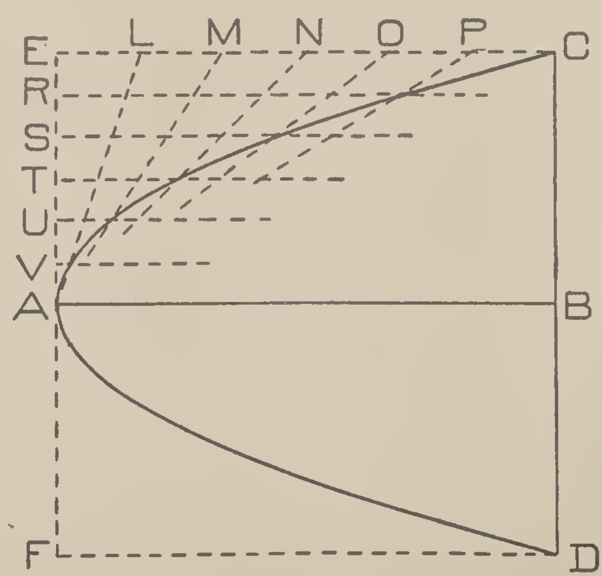
Problem 20



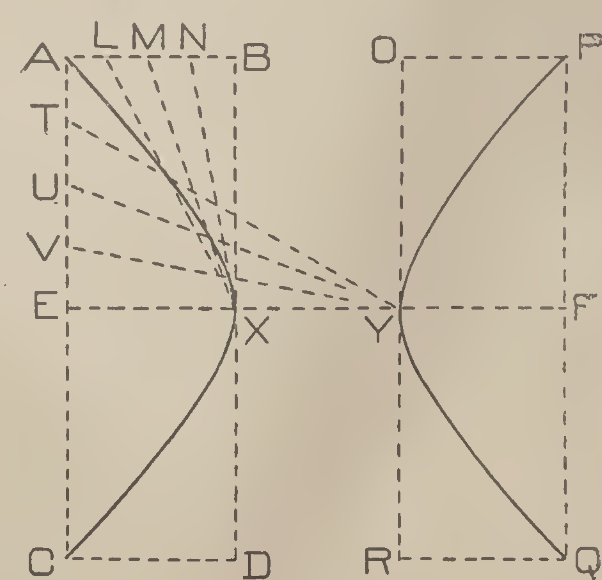
Problem 21



Problem 22



Problem 23



Problem 24

FEBRUARY 4, 1907 HERBERT CHANDLER CHICAGO, ILL.

points of intersection of the radii with the large circle C D E and F, draw *vertical* lines and from the intersection of the radii with the small circle C′, D′, E′, and F′, draw *horizontal* lines intersecting the vertical lines. The intersections of these lines are points on the curve.

As in Problem 19, a free hand curve should be sketched passing through these points. About five points in each quadrant will be sufficient.

PROBLEM 21. **To draw an Ellipse by means of a Trammel.**

As in the two preceding problems, draw the major and minor axes, U V and X Y. Take a slip of paper having a straight edge and mark off C B equal to one-half the major axis, and D B one-half the minor axis. Place the slip of paper in various positions keeping the point D on the major axis and the point C on the minor axis. If this is done the point B will mark various points on the curve. Find as many points as necessary and sketch the curve.

PROBLEM 22. **To draw a Spiral of one turn in a circle.**

Draw a circle with the center at O and a radius of $1\frac{1}{2}$ inches. Mark off on the radius O A, distances of one-eighth inch. As O A is $1\frac{1}{2}$ inches long there will be 12 of these distances. Draw circles through these points. Now draw radii O B, O C, O D, etc. each 30 degrees apart (use the 30 degree triangle). This will divide the circle into 12 equal parts. The curve starts at the center O. The next point is the intersection of the line O B and the first circle. The third point is the intersection of O C and the second circle. The fourth point is the intersection of O D and the third circle. Other points are found in the same way. Sketch in pencil the curve passing through these points.

PROBLEM 23. **To draw a Parabola when the Abscissa and Ordinate are given.**

Draw the straight line A B about three inches long. This line is the axis or as it is sometimes called the abscissa. At A and B draw lines perpendicular to A B. Also with the T square draw E C and F D, $1\frac{1}{2}$ inches above and below A B. Let A be

the vertex of the parabola. Divide A E into any number of equal parts and divide E C into the same number of equal parts. Through the points of division, R, S, T, U and V, draw horizontal lines and connect L, M, N, O and P, with A. The intersections of the horizontal lines with the oblique lines are points on the curve. For instance, the intersection of A L and the line V is one point and the intersection of A M and the line U is another.

The lower part of the curve A D is drawn in the same manner.

PROBLEM 24. **To draw a Hyperbola when the abscissa E X, the ordinate A E and the diameter X Y are given.**

Draw E F about 3 inches long and mark the point X, 1 inch from E and the point Y, 1 inch from X. With the triangle and T square, draw the rectangles A B D C and O P Q R, such that A B is 1 inch in length and A C, 3 inches in length. Divide A E into any number of equal parts and A B into the same number of equal parts. Draw L X, M X and N X; also connect T, U and V with Y. The first point on the curve is the intersection A; the next is the intersection of T Y and L X; the third the intersection of U Y and M X. The remaining points are found in the same manner. The curve X C and the right-hand curve P Y Q are found by repeating the process.

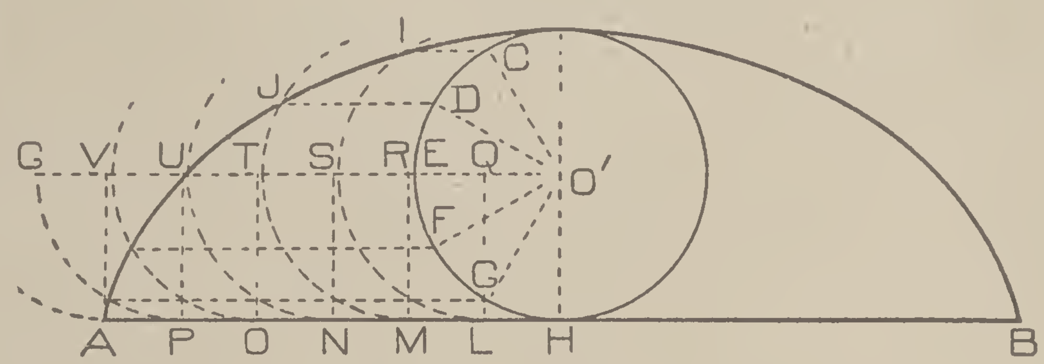
Inking. In inking the figures on this plate, use the French or irregular curve and make full lines for the curves and their axes. The construction lines should be dotted. Ink in all the construction lines used in finding one-half of a curve, and in Problems 19, 20, 23 and 24 leave all construction lines in *pencil* except those inked. In Problems 21 and 22 erase all construction lines not inked. The trammel used in Problem 21 may be drawn in the position as shown, or it may be drawn outside of the ellipse in any convenient place.

The same lettering should be done on this plate as on previous plates.

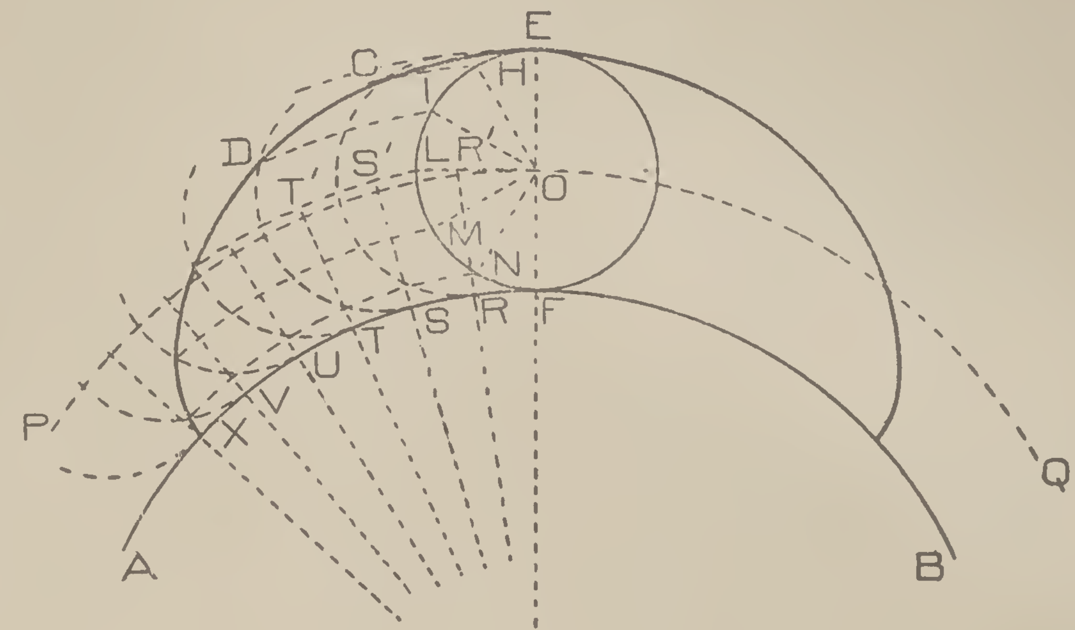
PLATE VIII.

Pencilling. In laying out Plate VIII, draw the border lines and horizontal and vertical center lines as in previous plates, to divide the plate into four spaces for the four problems.

PLATE VIII

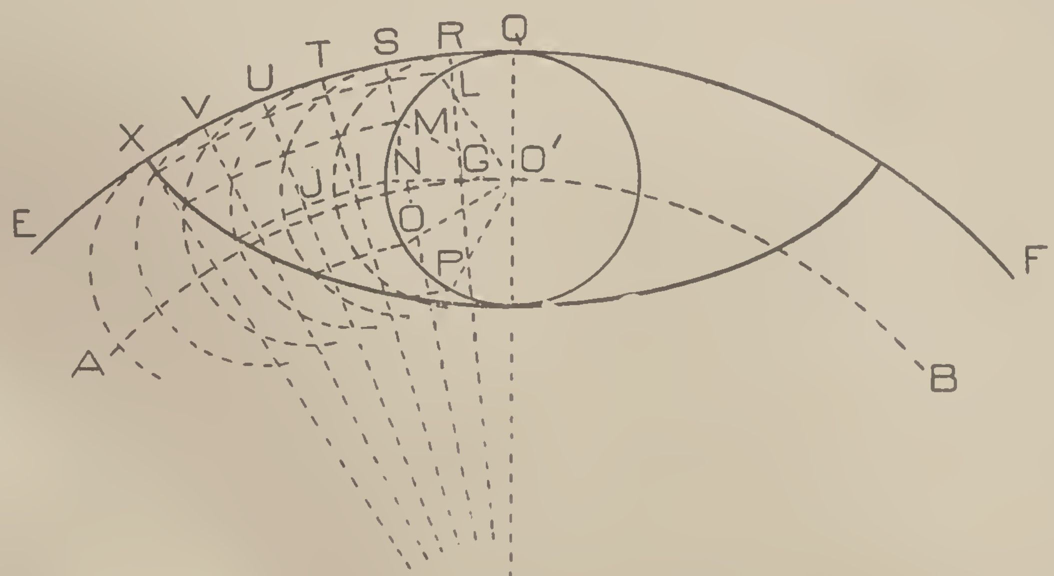


Problem 25



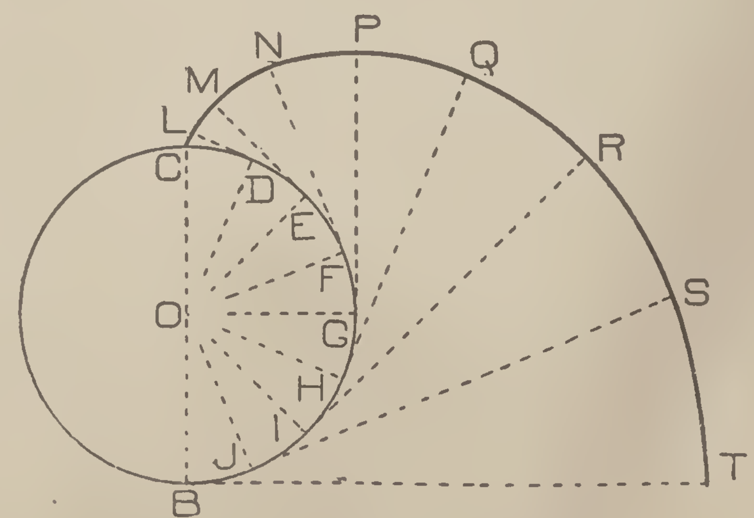
Problem 26

G



Problem 27

O



Problem 28

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PROBLEM 25. **To construct a Cycloid when the diameter of the generating circle is given.**

With O′ as a center and a radius of $\frac{7}{8}$ inch draw a circle, and tangent to it draw the indefinite horizontal straight line A B. Divide the circle into any number of equal parts (12 for instance) and through these points of division C, D, E, F, etc., draw horizontal lines. Now with the dividers set so that the distance between the points is equal to the chord of the arc C D, mark off the points L, M, N, O, P on the line A B, commencing at the point H. At these points erect perpendiculars to the center line G O′. This center line is drawn through the point O′ with the T square and is the line of centers of the generating circle as it rolls along the line A B. Now with the intersections Q, R, S, T, etc., of these verticals with the center line as centers describe arcs of circles as shown. The points on the curve are the intersections of these arcs and the horizontal lines drawn through the points C, D, E, F, etc. Thus the intersection of the arc whose center is Q and the horizontal line through C is a point I on the curve. Similarly, the intersection of the arc whose center is R and the horizontal line through D is another point J on the curve. The remaining points, as well as those on the right-hand side, are found in the same manner. To obtain great accuracy in this curve, the circle should be divided into a large number of equal parts, because the greater the number of divisions the less the error due to the difference in length of a chord and its arc.

PROBLEM 26. **To construct an Epicycloid when the diameter of the generating circle and the diameter of the director circle are given.**

The epicycloid and hypocycloid may be drawn in the same manner as the cycloid if arcs of circles are used in place of the horizontal lines. With O as a center and a radius of $\frac{3}{4}$ inch describe a circle. Draw the diameter E F of this circle and produce E F to G such that the line F G is $2\frac{3}{4}$ inches long. With G as a center and a radius of $2\frac{3}{4}$ inches describe the arc A B of the director circle. With the same center G, draw the arc P Q which will be the path of the center of the generating circle as it rolls along the arc A B Now divide the generating circle into

any number of equal parts (twelve for instance) and through the points of division H, I, L, M, and N, draw arcs having G as a center. With the dividers set so that the distance between the points is equal to the chord H I, mark off distances on the director circle A F B. Through these points of division R, S, T, U, etc., draw radii intersecting the arc P Q in the points R′, S′, T′, etc., and with these points as centers describe arcs of circles as in Problem 25. The intersections of these arcs with the arcs already drawn through the points H, I, L, M, etc., are points on the curve. Thus the intersection of the circle whose center is R′ with the arc drawn through the point H is a point upon the curve. Also the arc whose center is S′ with the arc drawn through the point I is another point on the curve. The remaining points are found by repeating this process.

PROBLEM 27. **To draw an Hypocycloid when the diameter of the generating circle and the radius of the director circle are given.**

With O as a center and a radius of 4 inches describe the arc E F, which is the arc of the director circle. Now with the same center and a radius of $3\frac{1}{4}$ inches, describe the arc A B, which is the line of centers of the generating circle as it rolls on the director circle. With O′ as a center and a radius of $\frac{3}{4}$ inch describe the generating circle. As before, divide the generating circle into any number of equal parts (12 for instance) and with these points of division L, M, N, O, etc., draw arcs having O as a center. Upon the arc E F, lay off distances Q R, R S, S T, etc., equal to the chord Q L. Draw radii from the points R, S, T, etc., to the center of the director circle O and describe arcs of circles having a radius equal to the radius of the generating circle, using the points G, I, J, etc., as centers. As in Problem 26, the intersections of the arcs are the points on the curve. By repeating this process, the right-hand portion of the curve may be drawn.

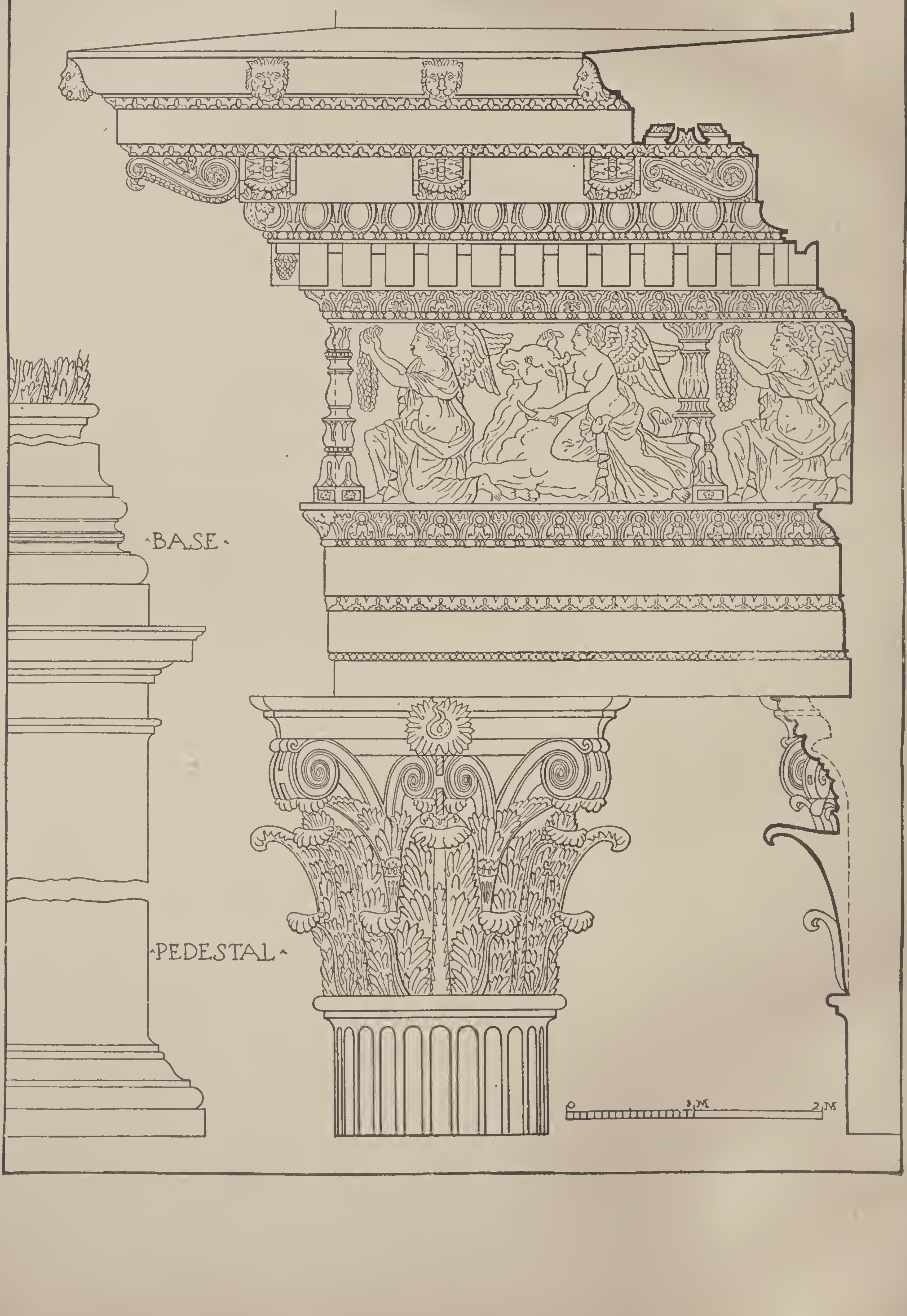
PROBLEM 28. **To draw the Involute of a circle when the diameter of the base circle is known.**

With point O as a center and a radius of 1 inch, describe the base circle. Now divide the circle into any number of equal parts 16 for instance) and connect the points of division with the cen-

ter of the circle by drawing the radii O C, O D, O E, O F, etc., to O B. At the point D, draw a light pencil line perpendicular to the radius O D This line will be tangent to the circle. Similarly at the points E, F, G, H, etc., draw tangents to the circle. Now set the dividers so that the distance between the points will be equal to the chord of the arc C D, and measure this distance from D along the tangent. Beginning with the point E, measure on the tangent a distance equal to two of these chords, from the point F measure on the tangent three divisions, and from the point G measure a distance equal to four divisions on the tangent G P. Similarly, measure distances on the remaining tangents, each time adding the length of the chord. This will give the points Q, R, S and T. Now sketch a light pencil line through the points L, M, N, P, etc., to T. This curve will be the involute of the circle.

Inking. The same rules are to be observed in inking *PLATE VIII* as were followed in the previous plates, that is, the curves should be inked in a full line, using the French or irregular curve. All arcs and lines used in locating the points on one-half of the curve should be inked in dotted lines. The arcs and lines used in locating the points of the other half of the curve may be left in pencil in Problems 25 and 26. In Problem 28, all construction lines should be inked. After completing the problems the same lettering should be done on this plate as on previous plates.

ROMAN CORINTHIAN ORDER



MECHANICAL DRAWING.

PART III.

PROJECTIONS.

ORTHOGRAPHIC PROJECTION.

Orthographic Projection is the art of representing objects of three dimensions by views on two planes at right angles to each other, in such a way that the forms and positions may be completely determined. The two planes are called planes of projection or co-ordinate planes, one being vertical and the other horizontal, as shown in Fig. 1. These planes are sometimes designated V and H respectively. The intersection of V and H is known as the ground line G L.

The view or projection of the figure on the plane gives the same appearance to the eye placed in a certain position that the object itself does. This position of the eye is at an infinite distance from the plane so that the rays from it to points of a limited object are all perpendicular to the plane. Evidently then the view of a point of the object is on the plane and in the ray through the point and the eye or where this perpendicular to the plane pierces it.

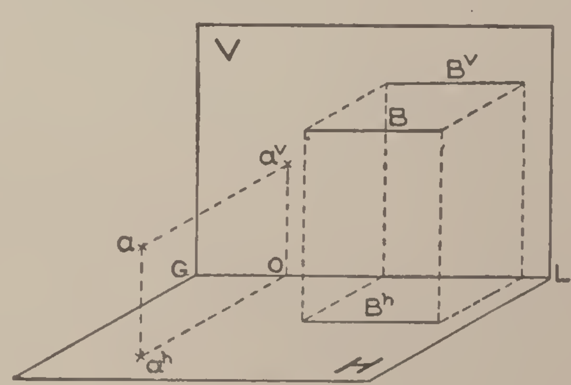


Fig. 1.

Let a, Fig. 1, be a point in space, draw a perpendicular from a to V. Where this line strikes the vertical plane, the projection of a is found, namely at a^v. Then drop a perpendicular from a to the horizontal plane striking it at a^h, which is the horizontal projection of the point. Drop a perpendicular from a^v to H; this will intersect G L at o and be parallel and equal to the line $a\,a^h$. In the same way draw a perpendicular from a^h to V, this also will intersect G L at o and will be parallel and equal to $a\,a^v$. In other words, the perpendicular to G L from the projection of a point on either plane equals the distance of the point from the other plane. B in Fig. 1, shows a line in space. B^v is its V projection, and B^h

its H projection, these being determined by finding views of points at its ends and connecting the points.

Instead of horizontal projection and vertical projection, the terms **plan** and **elevation** are commonly used.

Suppose a cube, one inch on a side, to be placed as in Fig. 2, with the top face horizontal and the front face parallel to the vertical plane. Then the plan will be a one-inch square, and the elevation also a one-inch square. In general the plan is a representation of the top of the object, and the elevation a view of the front. The plan then is a top view, and the elevation a front view.

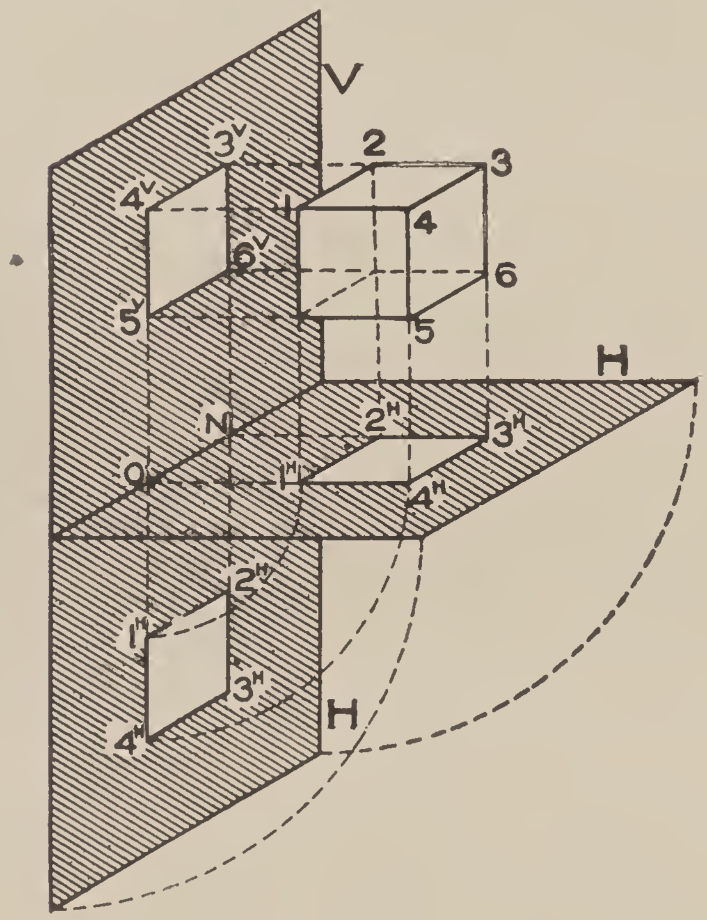


Fig. 2.

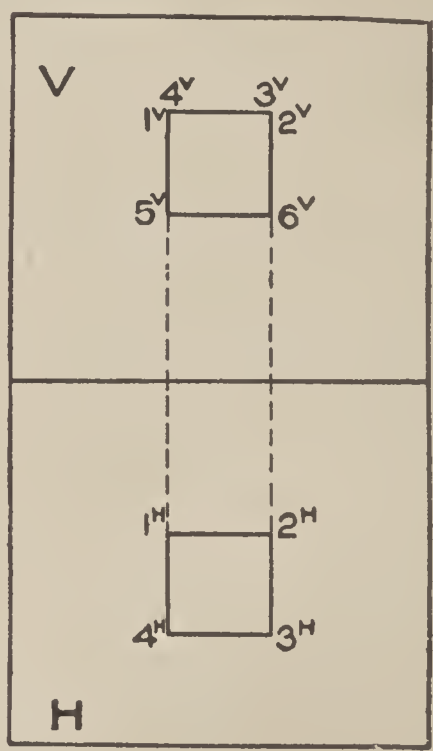


Fig. 3.

Thus far the two planes have been represented at right angles to each other, as they are in space. In order that they may be shown more simply and on the one plane of the paper, H is revolved about G L as an axis until it lies in the same plane as V as shown in Fig. 2. The lines 1^h O and 2^h N, being perpendicular to G L, are in the same straight line as 5^v O and 6^v N, which also are perpendicular to G L. That is—*two views of a point are always in a line perpendicular to G L.* From this it is evident that the plan must be vertically below the elevation, point for point. Now looking directly at the two planes in the revolved position, we

get a true orthographic projection of the cube as shown in Fig. 3.

All points on an object at the same height must appear in elevation at the same distance above the ground line. If numbers 1, 2, 3, and 4 on the plan, Fig. 3, indicate the top corners of the cube, then these four points, being at the same height, must be shown in elevation at the same height and at the top, $\frac{4^v}{1^v}$ and $\frac{3^v}{2^v}$. The top of the cube, 1, 2, 3, 4, is shown in elevation as the straight line $\frac{4^v}{1^v}\,\frac{3^v}{2^v}$. This illustrates the fact that *if a surface is perpendicular to either plane or projection, its projection on that plane is simply a line; a straight line if the surface is plane, a curved line if the surface is curved.* From the same figure it is seen that the top edge of the cube, 1 4, has for its projection on the vertical plane the point $\frac{4^v}{1^v}$, the principle of which is stated in this way: *If a*

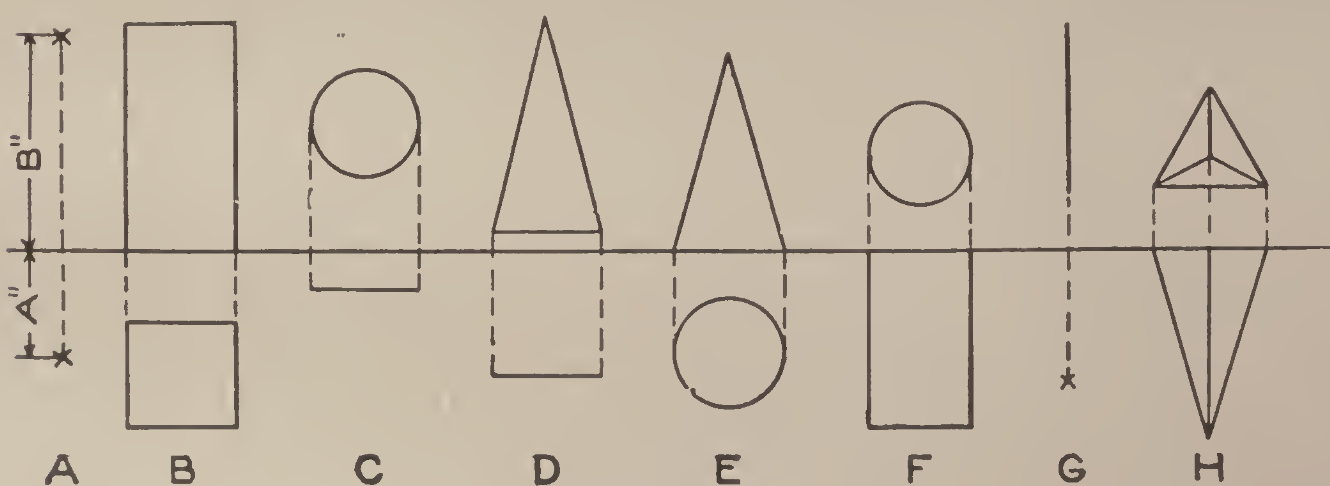


Fig. 4.

straight line is perpendicular to either V or H, its projection on that plane is a point, and on the other plane is a line equal in length to the line itself, and perpendicular to the ground line.

Fig. 4 is given as an exercise to help to show clearly the idea of plan and elevation.

A = a point B″ above H, and A″ in front of V.
B = square prism resting on H, two of its faces parallel to V.
C = circular disc in space parallel to V.
D = triangular card in space parallel to V.
E = cone resting on its base on H.
F = cylinder perpendicular to V, and with one end resting against V.
G = line perpendicular to H.
H = triangular pyramid above H, with its base resting against V.

Suppose in Fig. 5, that it is desired to construct the projections of a prism $1\frac{1}{2}$ in. square, and 2 in. long, standing on one end on the horizontal plane, two of its faces being parallel to the vertical plane. In the first place, as the top end of the prism is a square, the top view or plan will be a square of the same size, that is, $1\frac{1}{2}$ in. Then since the prism is placed parallel to and in front of the vertical plane the plan, $1\frac{1}{2}$ in. square, will have two edges parallel to the ground line. As the front face of the prism

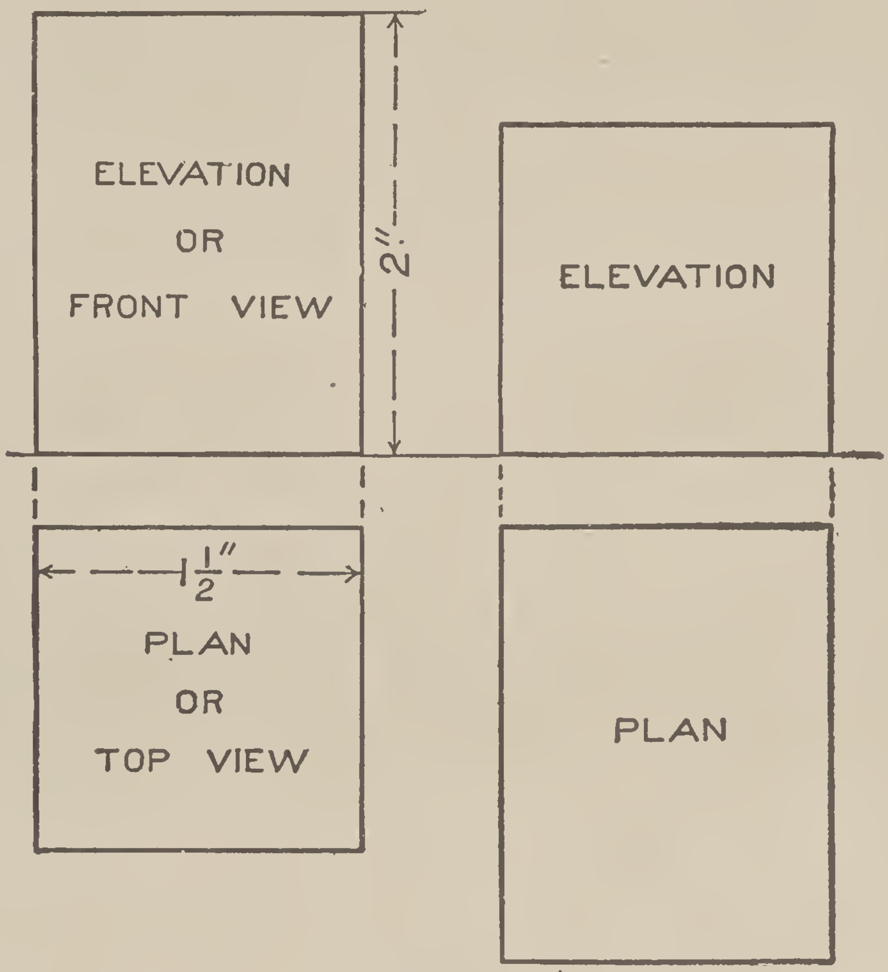


Fig. 5.

is parallel to the vertical plane its projection on V will be a rectangle, equal in length and width to the length and width respectively of the prism, and as the prism stands with its base on H, the elevation, showing height above H, must have its base on the ground line. Observe carefully that points in elevation are vertically over corresponding points in plan.

The second drawing in Fig. 5 represents a prism of the same size lying on one side on the horizontal plane, and with the ends parallel to V.

The principles which have been used thus far may be stated as follows, —

1. If a line or point is on either plane, its other projection must be in the ground line.

2. Height above H is shown in elevation as height above the ground line, and distance in front of the vertical plane is shown in plan as distance from the ground line.

3. If a line is parallel to either plane, its actual length is shown on that plane, and its other projection is parallel to the ground line. A line oblique to either plane has its projection on that plane shorter than the line itself, and its other projection oblique to the ground line. No projection can be longer than the line itself.

4. A plane surface if parallel to either plane, is shown on

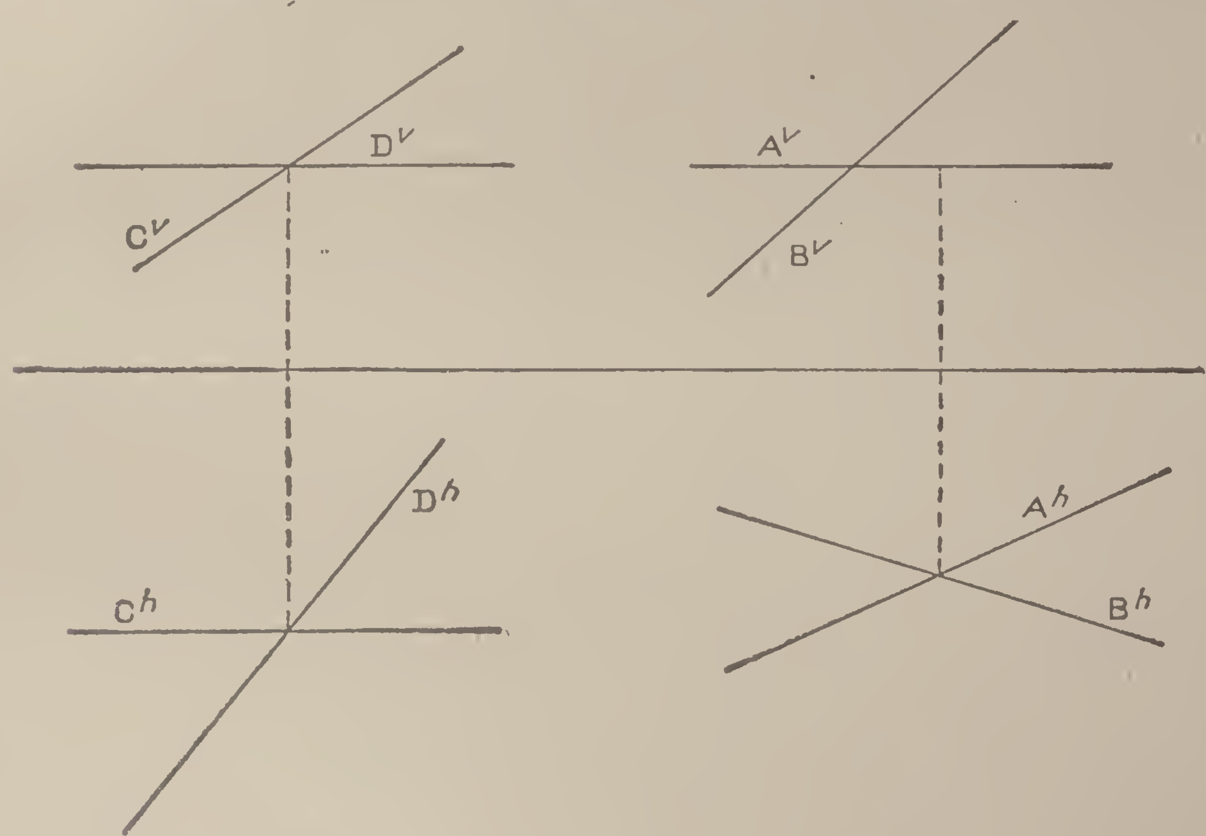


Fig. 6.　　Fig. 7.

that plane in its true size and shape; if oblique it is shown smaller than the true size, and if perpendicular it is shown as a straight line. Lines parallel in space must have their V projections parallel to each other and also their H projections.

If two lines intersect, their projections must cross, since the point of intersection of the lines is a point on both lines, and therefore the projections of this point must be on the projections of both lines, or at their intersection. In order that intersecting lines may be represented, the vertical projections must intersect in a point vertically above the intersection of the horizontal pro-

jections. Thus Fig. 6 represents two lines which do intersect as C^v crosses D^v at a point vertically above the intersection of C^h and D^h. In Fig. 7, however, the lines do not intersect since the intersections of their projections do not lie in the same vertical line.

In Fig. 8 is given the plan and elevation of a square pyramid standing on the horizontal plane. The height of the pyramid is the distance A B. The slanting edges of the pyramid, A C, A D, etc., must be all of the same length, since A is directly above the center of the base. What this length is, however, does not appear in either projection, as these edges are not parallel to either V or H.

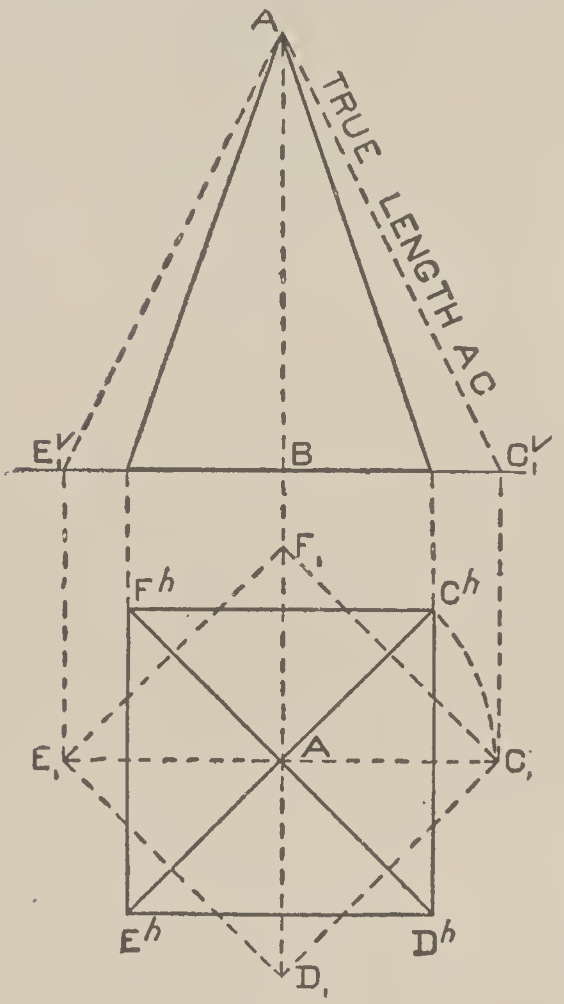
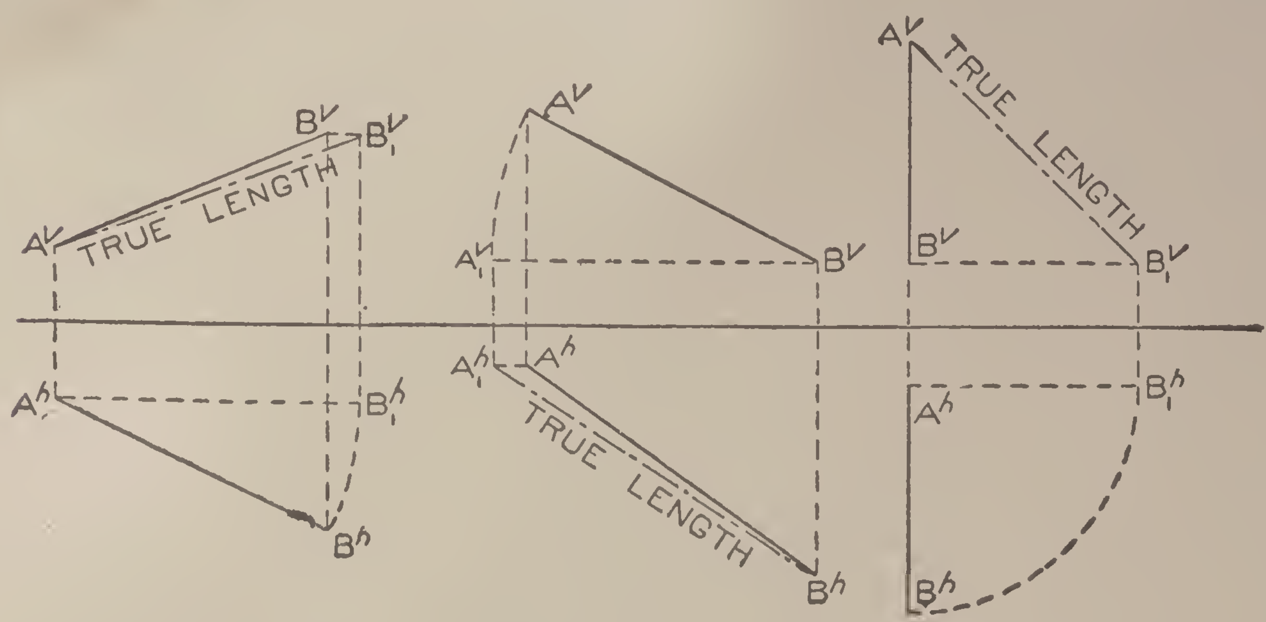


Fig. 8.

Suppose that the pyramid be turned around into the dotted position C_1 D_1 E_1 F_1 where the horizontal projections of two of the slanting edges, A C_1 and A E_1 are parallel to the ground line. These two edges, having their horizontal projections parallel to the ground line, are now parallel to V, and therefore their new vertical projections will show their true lengths. The base of the pyramid is still on H, and therefore is projected on V in the ground line. The apex is in the same place as before, hence the vertical projection of the pyramid in its new position is shown by the dotted lines. The vertical projection A C_1^v is the true length of edge A C. Now if we wish to find simply the true length of A C, it is unnecessary to turn the whole pyramid around, as the one line A C will be sufficient.

The principle of finding the true length of lines is this, and can be applied to any case: Swing one projection of the line parallel to the ground line, using one end as center. On the other projection the moving end remains at the same distance from the ground line, and of course vertically above or below the same end in its parallel position. This new projection of the line shows its true length. See the three Figures at the top of page 9.

Third plane of projection or profile plane. A plane perpendicular to both co-ordinate planes, and hence to the ground line, is



called a *profile plane.* This plane is vertical in position, and may be used as a plane of projection. A projection on the profile plane is called a profile view, or *end view*, or sometimes edge view, and is often required in machine or other drawing when the plan and elevation do not sufficiently give the shape and dimensions.

A projection on this plane is found in the same way as on the

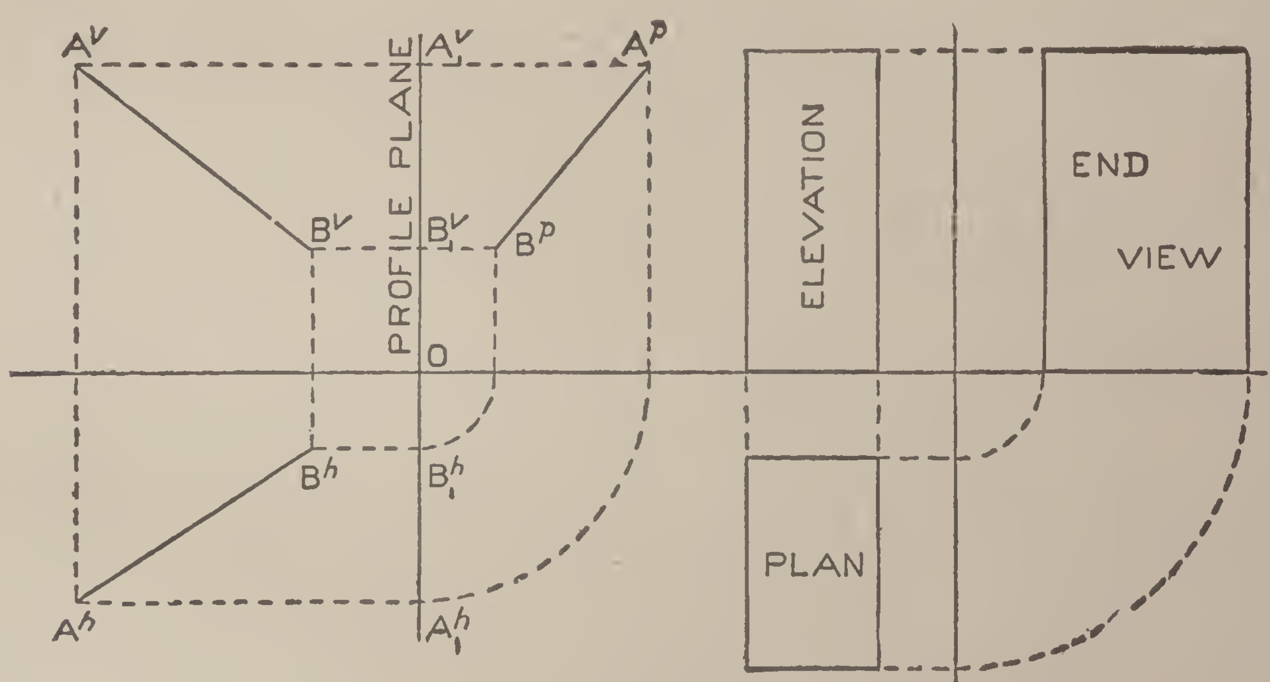


Fig. 9.

V plane, that is, by perpendiculars drawn from points on the object.

Since, however, the profile plane is perpendicular to the ground line, it will be seen from the front and top simply as a

straight line; in order that the size and shape of the profile view may be shown, the profile plane is revolved into V using its intersection with the vertical plane as the axis.

Given in Fig. 9, the line A B by its two projections A^v B^v and A^h B^h, and given also the profile plane. Now by projecting the line on the profile by perpendiculars, the points $A_1{}^v$ $B_1{}^v$ and $B_1{}^h$ $A_1{}^h$ are found. Revolving the profile plane like a door on its hinges, all points in the plane will move in horizontal circles, so the horizontal projections $A_1{}^h$ and $B_1{}^h$ will move in arcs of circles with O as center to the ground line, and the vertical projections $B_1{}^v$ and $A_1{}^v$ will move in lines parallel to the ground line to positions directly above the revolved points in the ground line, giving the profile view of the line A^p B^p. Heights, it will be seen, are the same in profile view as in elevation. By referring to the rectangular prism in the same figure, we see that the elevation gives vertical dimensions and those parallel to V, while the end view shows vertical dimensions and those perpendicular to V. The profile view of any object may be found as shown for the line A B by taking one point at a time.

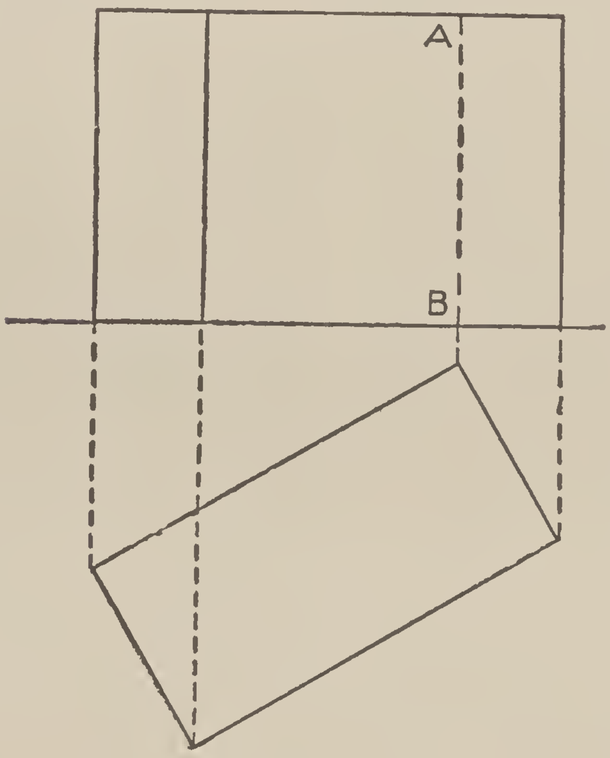


Fig. 10.

In Fig. 10 there is represented a rectangular prism or block, whose length is twice the width. The elevation shows its height. As the prism is placed at an angle, three of the vertical edges will be visible, the fourth one being invisible.

In mechanical drawing lines or edges which are invisible are drawn *dotted*. The edges which in projection form a part of the outline or contour of the figure must always be visible, hence always *full lines*. The plan shows what lines are visible in elevation, and the elevation determines what are visible in plan. In Fig. 10, the plan shows that the dotted edge A B is the back edge, and in Fig. 11, the dotted edge C D is found, by looking at the elevation, to be the lower edge of the triangular prism. In general,

if in elevation an edge projected *within* the figure is a back edge, it must be dotted, and in plan if an edge projected within the outline is a lower edge it is dotted.

Fig. 12 is a circular cylinder with the length vertical and

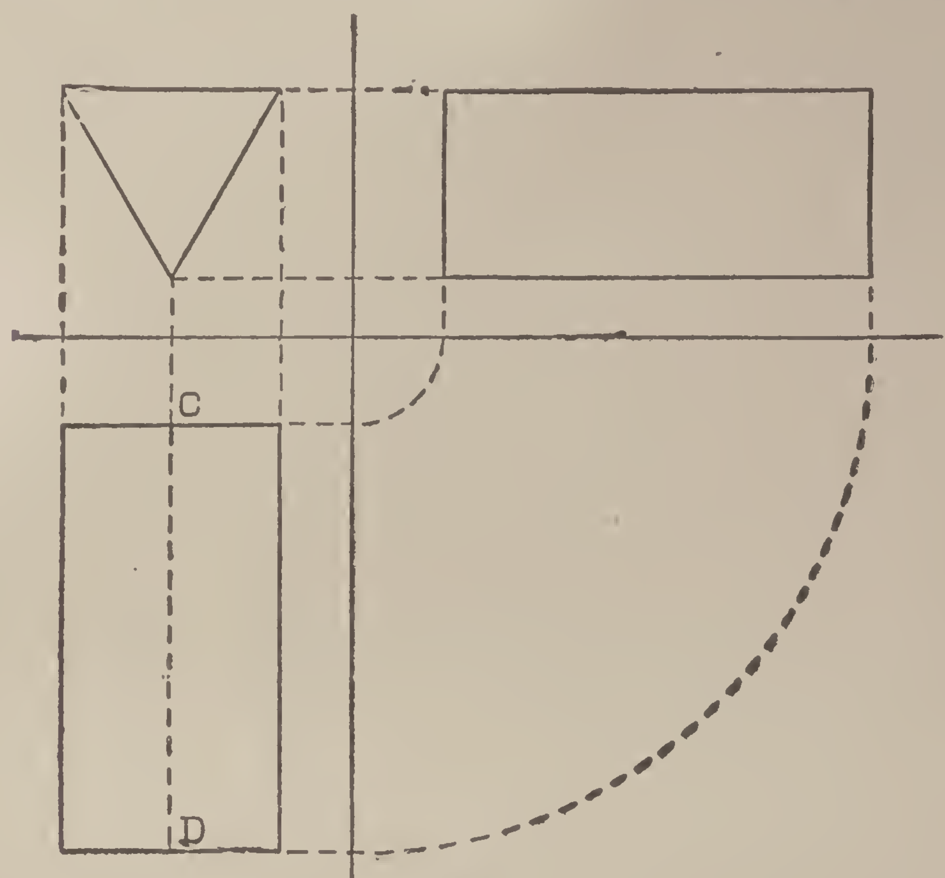


Fig. 11.

with a hole part way through as shown in elevation. Fig. 13 is plan, elevation and end view of a triangular prism with a square hole from end to end. The plan and elevation alone would be insufficient to determine positively the shape of the hole, but the end view shows at a glance that it is square.

In Fig. 14 is shown plan and elevation of the frustum of a square pyramid, placed with its base on the horizontal plane. If the frustum is turned through 30°, as shown in the plan of Fig. 15, the top view or plan must still be the same shape and size, and as the frustum has not been raised or lowered, the heights of all points must appear the same in elevation as before in Fig. 14. The elevation is easily found by projecting points up from the plan, and projecting the height of the top horizontally across from the first elevation, because the height does not change.

The same principle is further illustrated in Figs. 16 and 17. The elevation of Fig. 16 shows a square prism resting on one edge, and raised up at an angle of 30° on the right-hand side. The

plan gives the width or thickness, $\frac{5}{8}$ in. Notice that the length of the plan is greater than 2 in. and that varying the angle at

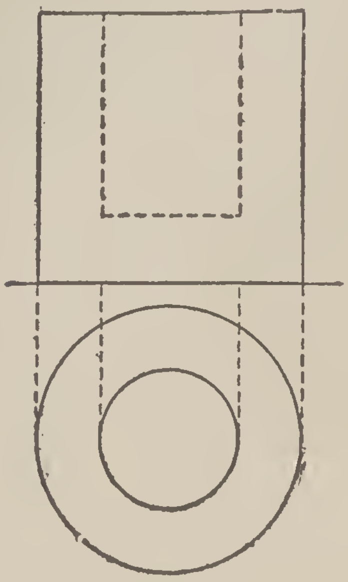


Fig. 12.

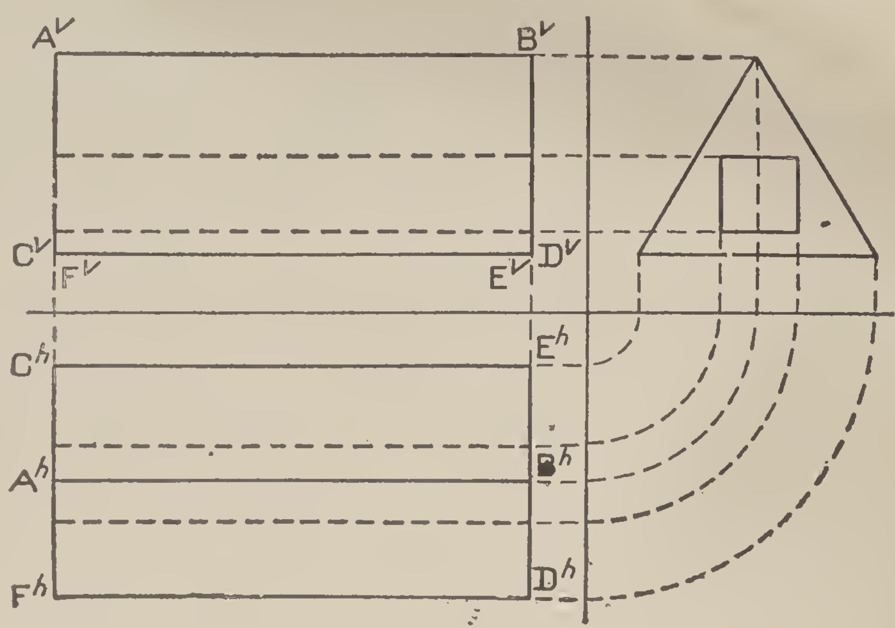


Fig. 13.

which the prism is slanted would change the length of the plan. Now if the prism be turned around through any angle with the vertical plane, the lower edge still being on H, and the inclination

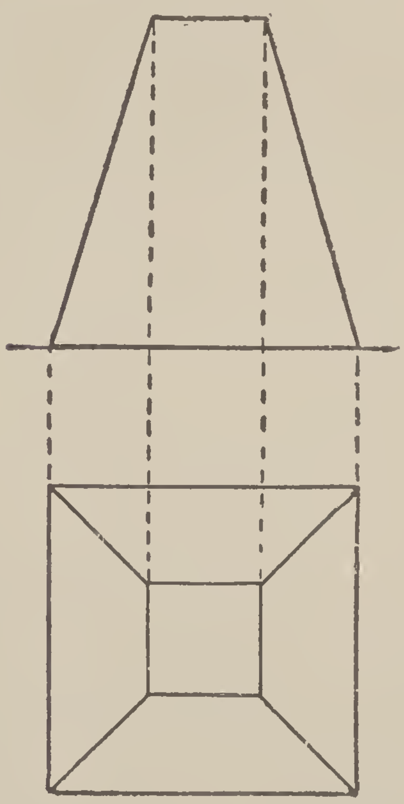


Fig. 14.

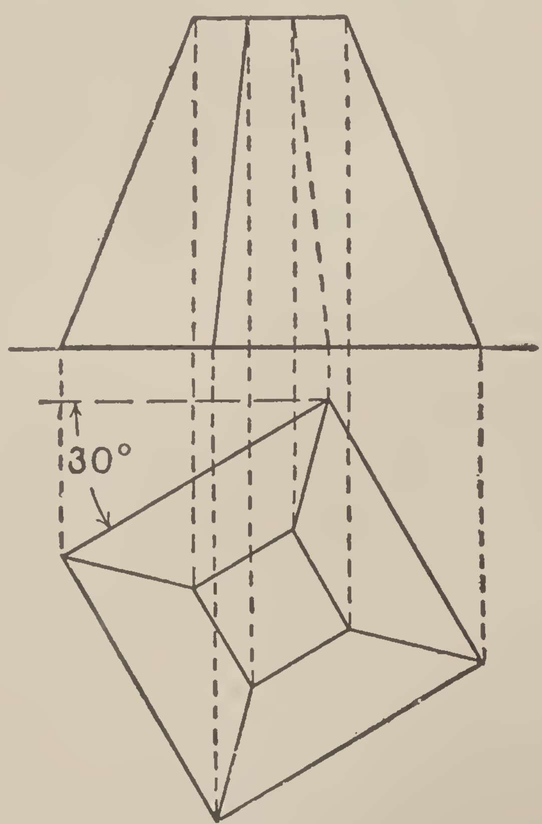


Fig. 15.

of 30° with H remaining the same, the plan must remain the same size and shape.

If the angle through which the prism be turned is 45°, we

have the second plan, exactly the same shape and size as the first. The elevation is found by projecting the corners of the prism ver

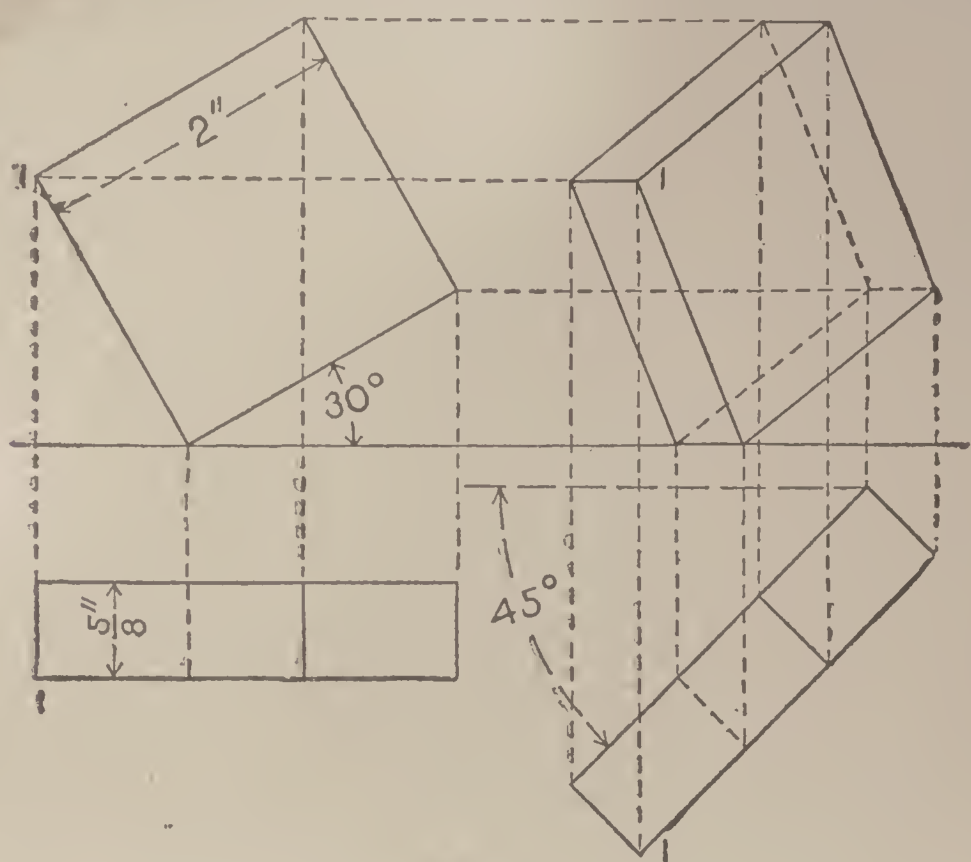


Fig. 16.

tically up to the heights of the same points in the first elevation. All the other points are found in the same way as point No. 1.

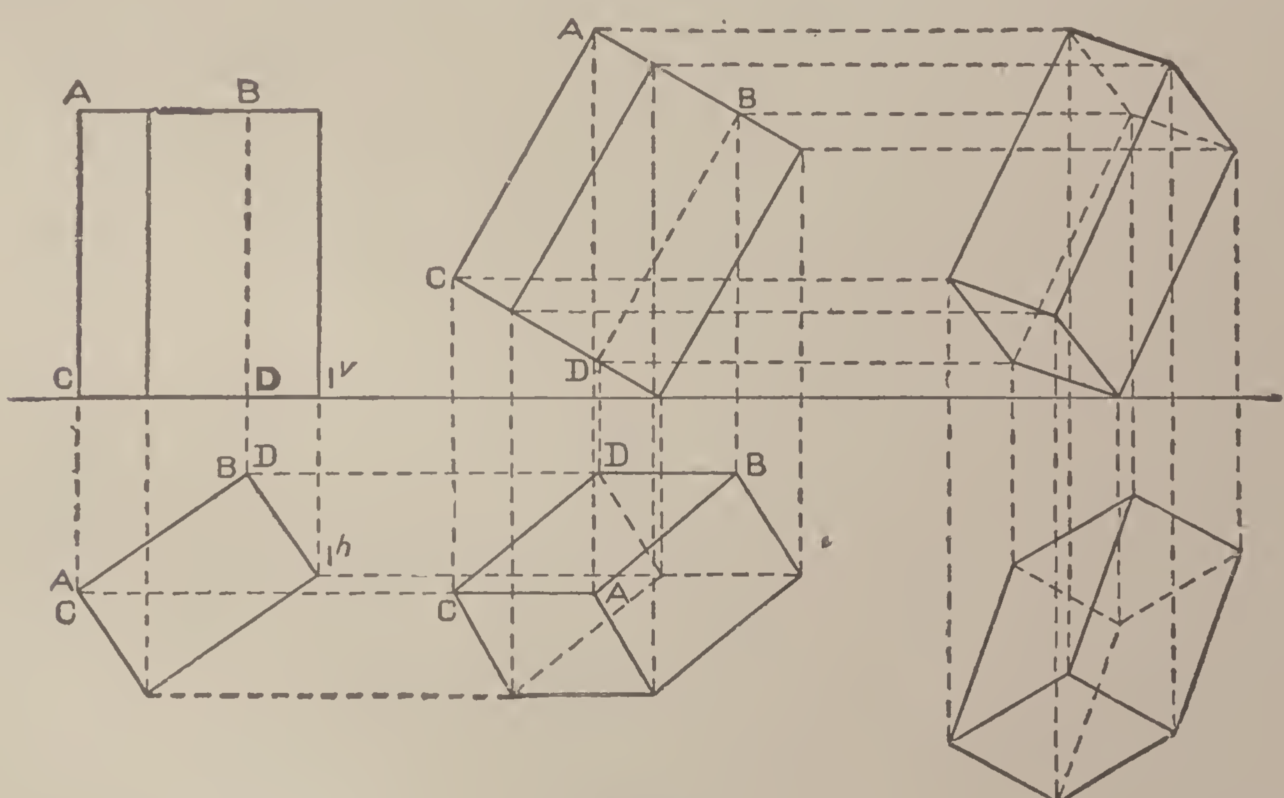


Fig. 17.

Three positions of a rectangular prism are shown in Fig. 17. In the first view, the prism stands on its base, its axis therefore

is parallel to the vertical plane. In the second position, the axis is still parallel to V and one corner of the base is on the horizontal plane. The prism has been turned as if on the line $1^h\ 1^v$ as an axis, so that the inclination of all the faces of the prism to the vertical plane remains the same as before. That is, if in the first figure the side A B C D makes an angle of 30° with the vertical, the same side in the second position still makes 30° with the ver-

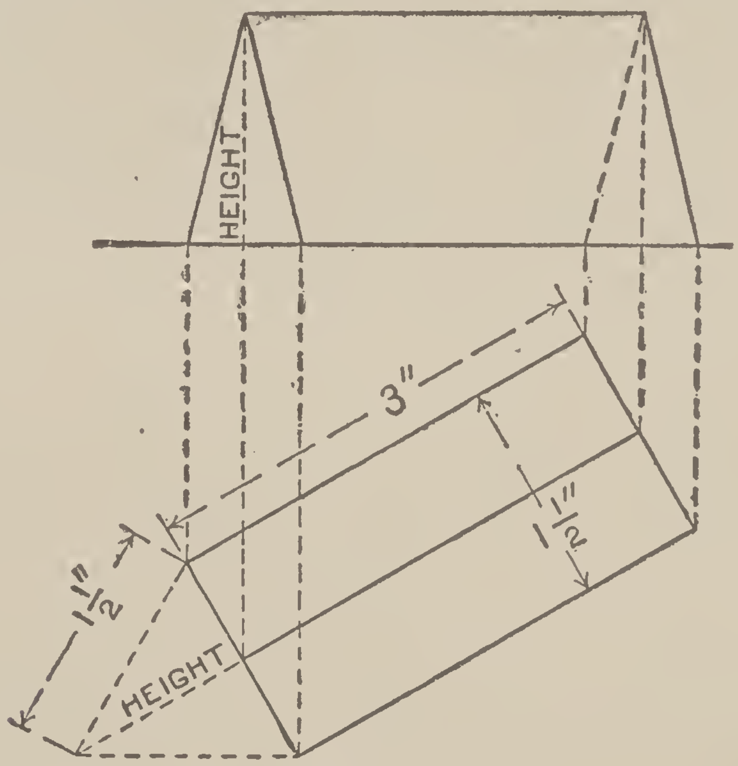


Fig. 18.

tical plane. Hence the elevation of No. 2 is the same shape and size as in the first case. The plan is found by projecting the corners down from the elevation to meet horizontal lines projected across from the corresponding points in the first plan. The third position shows the prism with all its faces and edges making the same angles with the horizontal as in the second position, but with the plan at a different angle with the ground line. The plan then is the same shape and size as in No. 2, and the elevation is found by projecting up to the same heights as shown in the preceeding elevation. This principle may be applied to any solid, whether bounded by plane surfaces or curved.

This principle as far as it relates to heights, is the same that was used for profile views. An end view is sometimes necessary before the plan or elevation of an object can be drawn. Suppose that in Fig. 18 we wish to draw the plan and elevation of a triangular prism 3″ long, the end of which is an equilateral triangle

$1\frac{1}{2}''$ on each side. The prism is lying on one of its three faces on H, and inclined toward the vertical plane at an angle of 30°. We are able to draw the plan at once, because the width will be $1\frac{1}{2}$ inches, and the top edge will be projected half way between the other two. The length of the prism will also be shown. Before we can draw the elevation, we must find the height of the top edge. This height, however, must be equal to the altitude of the triangle forming the end of the prism. All that is necessary, then, is to construct an equilateral triangle $1\frac{1}{2}''$ on each side, and measure its altitude.

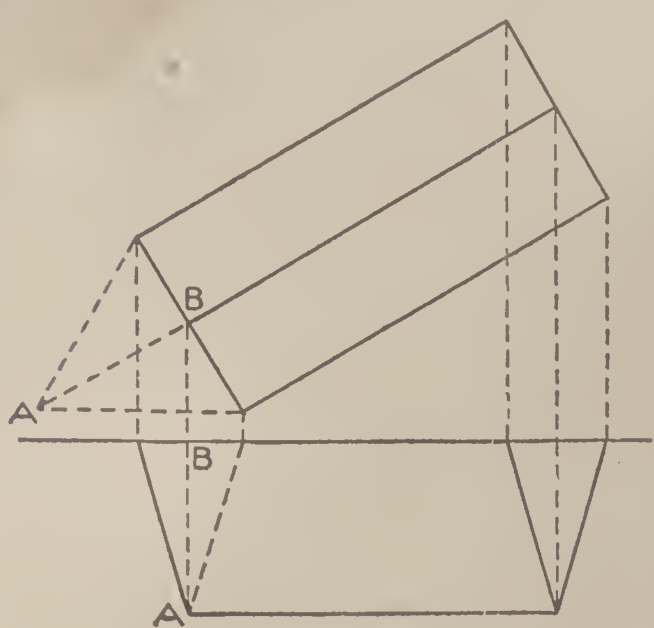


Fig. 19.

A very convenient way to do this is shown in the figure by laying one end of the prism down on H. A similar construction is shown in Fig. 19, but with one face of the prism on V instead of on H.

In all the work thus far the plan has been drawn below and the elevation above. This order is sometimes inverted and the plan put above the elevation, but the plan still remains a top view no matter where placed, so that after some practice it makes but little difference to the draughtsman which method is employed.

SHADE LINES.

It is often the case in machine drawing that certain lines or edges are made heavier than others. These heavy lines are called shade lines, and are used to improve the appearance of the drawing, and also to make clearer in some cases the shape of the object. The shade lines are not put on at random, but according to some system. Several systems are in use, but only that one which seems most consistent will be described. The shade lines are lines or edges separating light faces from dark ones, assuming the light always to come in a direction parallel to the dotted diagonal of the cube shown in Fig. 20. The direction of the light, then, may be represented on H by a line at 45° running

backward to the right and on V by a 45° line sloping downward and to the right. Considering the cube in Fig. 20, if the light comes in the direction indicated, it is evident that the front, left-hand side and top will be light, and the bottom, back and right-hand side dark. On the plan, then, the shade lines will be the back edge 1 2 and the right-hand edge 2 3, because these edges are between light faces and dark ones. On the elevation, since the front is light, and the right-hand side and bottom dark, the edges 3 7 and 8 7 are shaded. As the direction of the light is represented on the plan by 45° lines and on the elevation also by 45° lines,

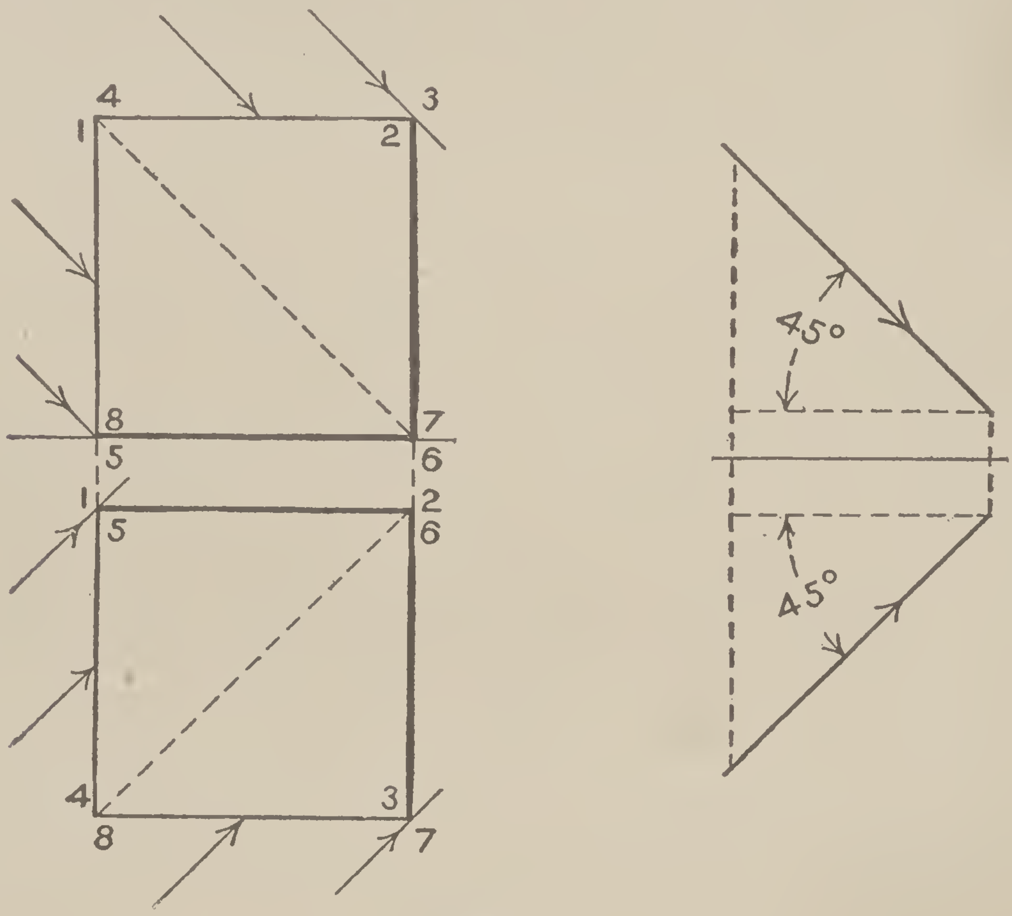


Fig. 20.

we may use the 45° triangle with the T-square to determine the light and dark surfaces, and hence the shade lines. If the object stands on the horizontal plane, the 45° triangle is used on the plan, as shown in Fig. 21, but if the length is perpendicular to the vertical plane, the 45° triangle is used on the elevation, as shown in Fig. 22. This is another way of saying that the 45° triangle is used on that projection of the object which shows the end. By applying the triangle in this way we determine the light and dark surfaces, and then put the shade lines between them. Dotted lines, however, are never shaded, so if a line which is between a light and a dark surface is invisible it is not

shaded. In Fig. 21 the plan shows the end of the solid, hence the 45° triangle is used in the direction indicated by the arrows.

This shows that the light strikes the left-hand face, but not the back or the right-hand. The top is known to be light with-

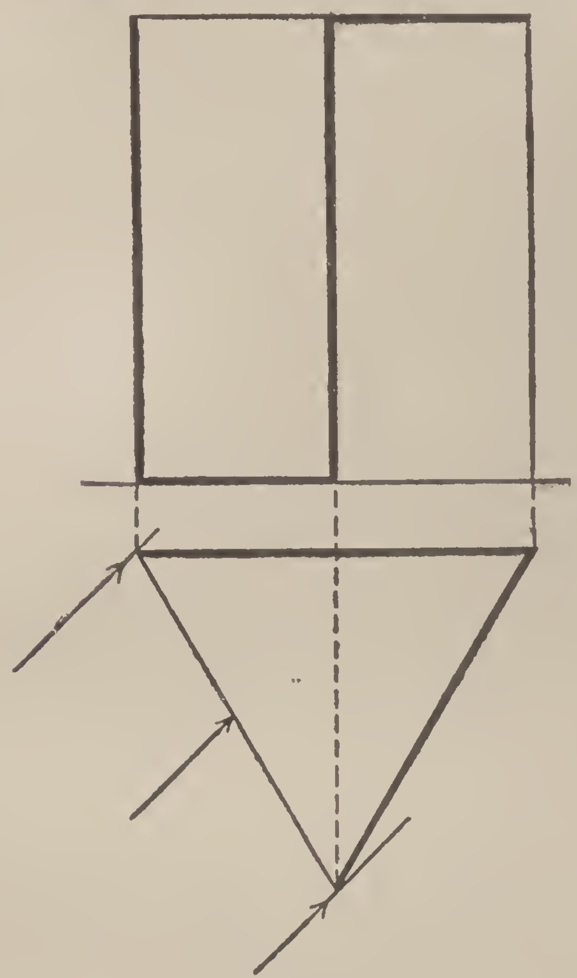


Fig. 21.

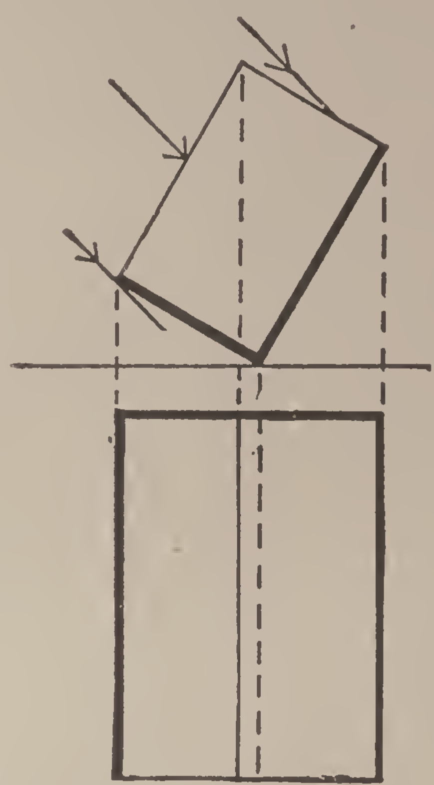


Fig. 22.

out the triangle, as the light comes downward, so the shade edges on the plan are the back and right-hand. On the elevation two faces of the prism are visible; one is light, the other dark, hence the edge between is shaded. The left-hand edge, being between a light face and a dark one is a shade line. The right-hand face is dark, the top of the prism is light, hence the upper edge of this face is a shade line. The right-hand edge is not shaded, because by referring to the plan, it is seen to be between two dark surfaces. In shading a cylinder or a cone the same rule is followed, the only difference being that as the surface is curved, the light is tangent, so an element instead of an edge marks the separation of the dark from the light, and is *not* shaded. The elements of a cylinder or cone should *never* be shaded, but the bases may. In Fig. 23, Nos. 3 and 4, the student should carefully notice the difference between the shading of the cone and cylinder.

If in No. 4 the cone were inverted, the opposite half of the base would be shaded, for then the base would be light, whereas it is now dark. In Nos. 7 and 8 the shade lines of a cylinder and a circular hole are contrasted.

In No. 7 it is clear that the light would strike inside on the further side of the hole, commencing half way where the 45° lines

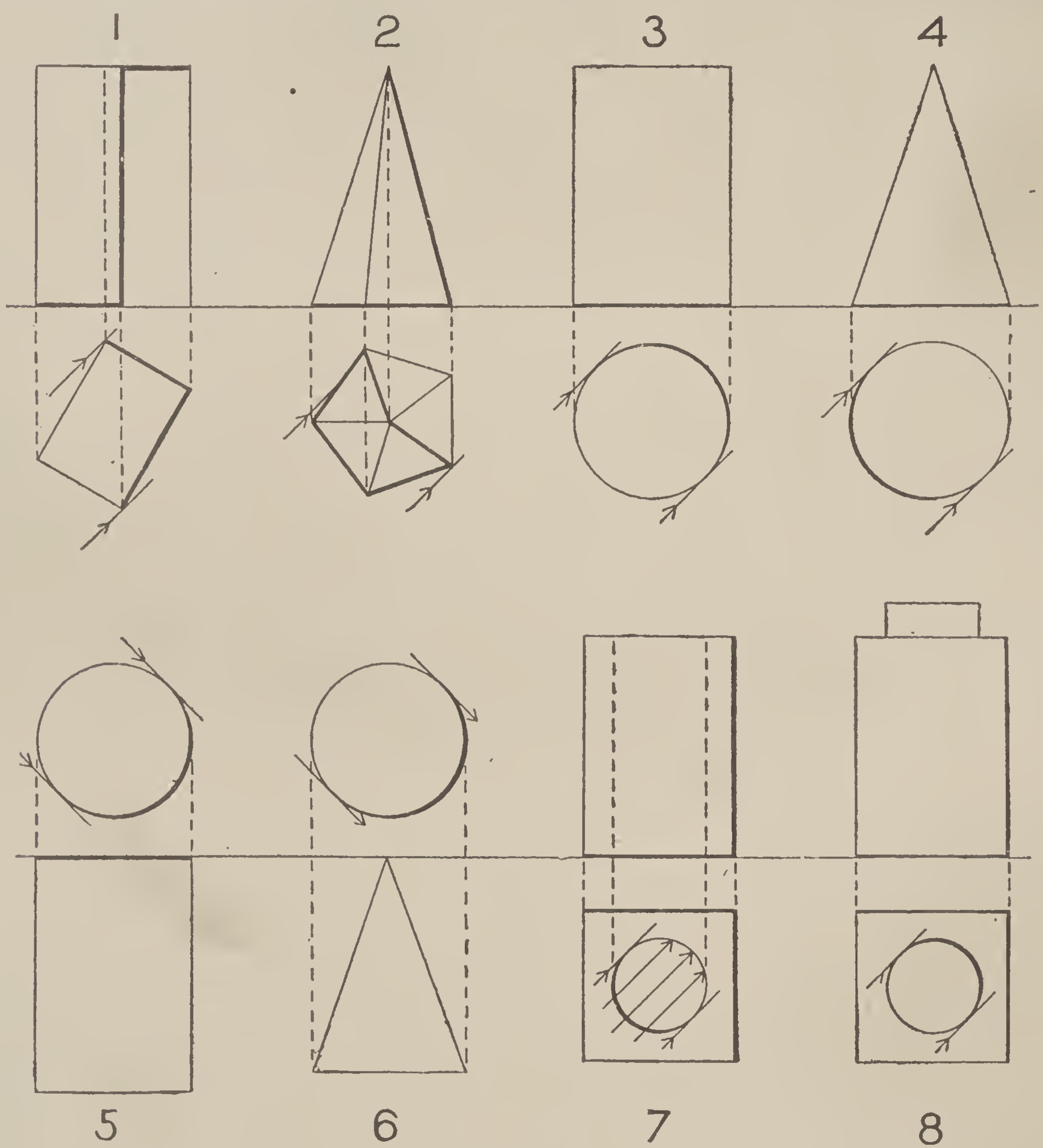


Fig. 23.

are tangent. The other half of the inner surface would be dark, hence the position of the shade line. The shade line then enables us to tell at a glance whether a circle represents a hub or boss, or depression or hole. Fig. 24 represents plan, elevation and profile view of a square prism. Here as before, the view showing the end is the one used to determine the light and dark surfaces, and then the shade lines put in accordingly.

In putting on the shade lines, the extra width of line is put *inside* the figure, not outside. In shading circles, the shade line is made of varying width, as shown in the figures. The method of obtaining this effect by the compass is to keep the same radius, but to change the center slightly in a direction parallel to the rays of light, as shown at A and B in No. 2 of Fig. 24.

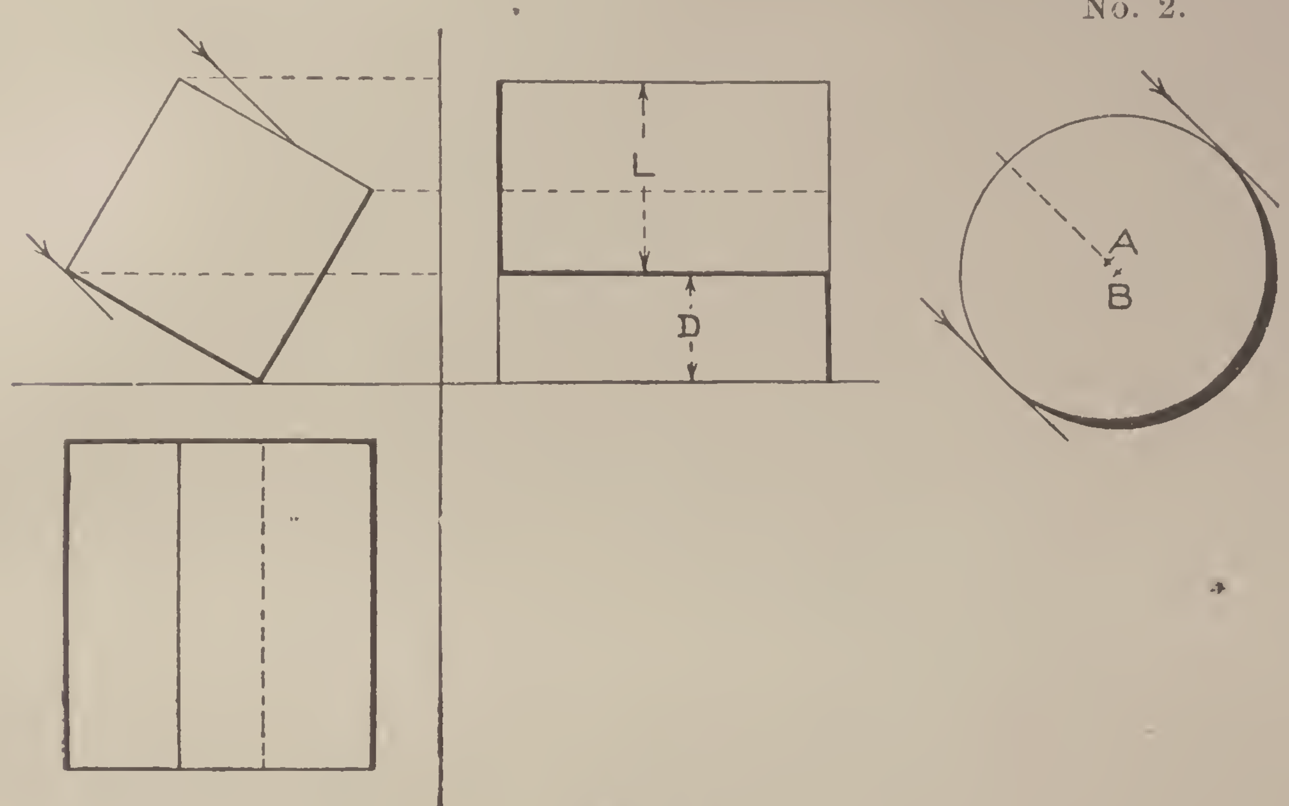


Fig. 24.

INTERSECTION AND DEVELOPMENT.

If one surface meets another at some angle, an intersection is produced. Either surface may be plane, or curved. If both are plane, the intersection is a straight line; if one is curved, the intersection is a curve, except in a few special cases; and if both are curved, the intersection is usually curved.

In the latter case, the entire curve does not always lie in the same planes. If all points of any curve lie in the same plane, it is called a plane curve. A plane intersecting a curved surface must always give either a plane curve or a straight line.

In Fig. 25 a square pyramid is cut by a plane A parallel to the horizontal. This plane cuts from the pyramid a four-sided figure, the four corners of which will be the points where A cuts the four slanting edges of the solid. The plane intersects edge $o\ b$ at point $4v$ in elevation. This point must be found in plan vertically below on

the horizontal projection of line *o b*, that is, at point 4^h. Edge *o e* is directly in front of *o b*, so is shown in elevation as the same line, and plane A intersects *o e* at point 1^v in elevation, found in plan at 1^h. Points 3 and 2 are obtained in the same way. The intersection is shown in plan as the square 1 2 3 4, which is also its true size as it is parallel to the horizontal plane. In a similar way the sections are found in Figs. 26 and 27. It will be seen that in these three cases where the planes are parallel to the bases, the sections are of the same shape as the bases, and have their sides parallel to the edges of the bases.

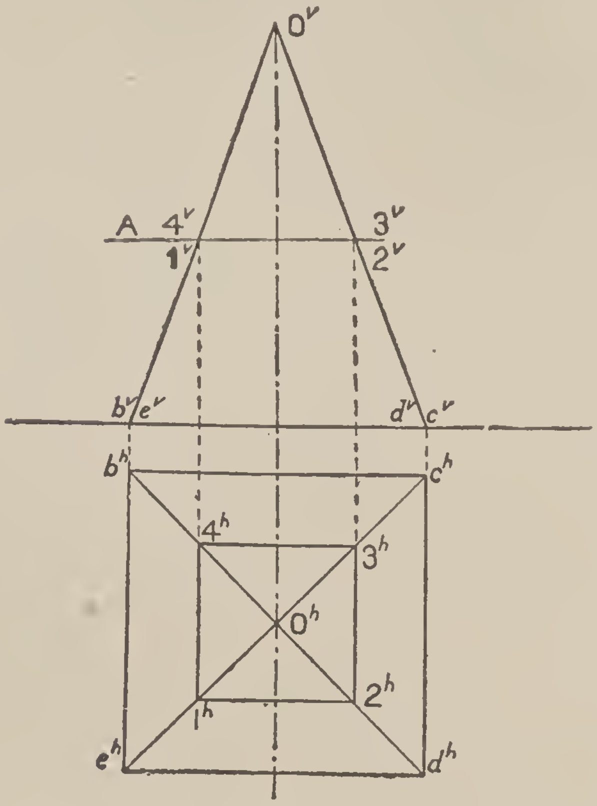


Fig. 25.

It is an invariable rule that when such a solid is cut by a plane parallel to its base, the section is a figure of the same shape as the base. If then in Fig. 28 a right cone is intersected by a plane parallel to the base the section must be a circle, the center of which in plan coincides with the apex. The radius must equal *o d*.

In Figs. 29 and 30 the cutting plane is not parallel to the base, hence the intersection will not be of the same shape as the base. The sections are found, however, in exactly the same manner as in the previous figures, by projecting the points where the plane intersects the edges in elevation on to the other view of the same line.

INTERSECTION OF PLANES WITH CONES OR CYLINDERS.

Sections cut by a plane from a cone have already been defined as *conic sections*. These sections may be either of the following: two straight lines, circle, ellipse, parabola, hyperbola. All except the parabola and hyperbola may also be cut from a cylinder.

Methods have previously been given for constructing the

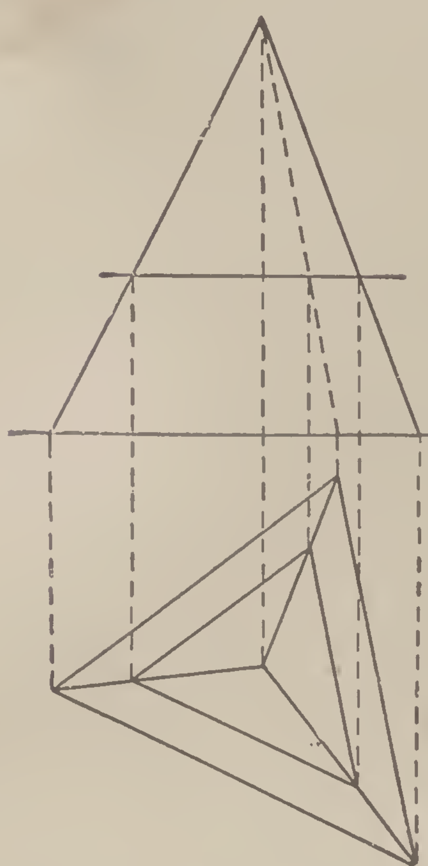


Fig. 26.

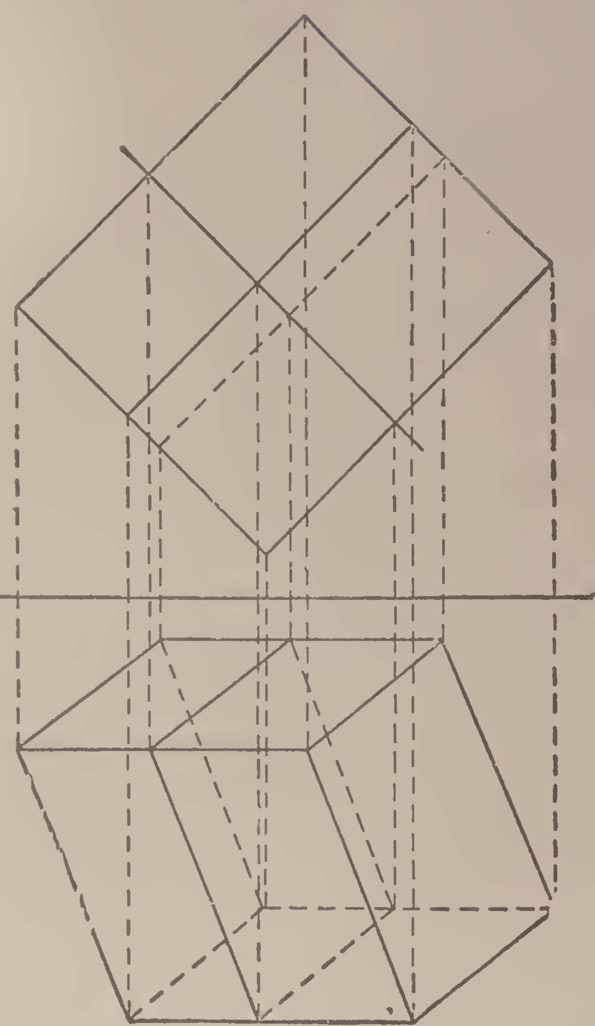


Fig. 27.

Fig. 28.

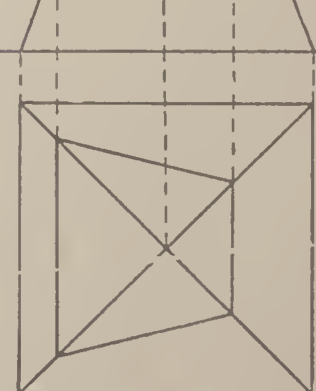


Fig. 29.

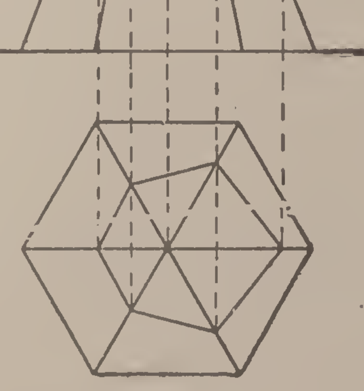


Fig. 30.

ellipse, parabola and hyperbola without projections; it will now be shown that they may be obtained as actual intersections.

In Fig. 31 the plane cuts the cone obliquely. To find points on the curve in plan take a series of horizontal planes

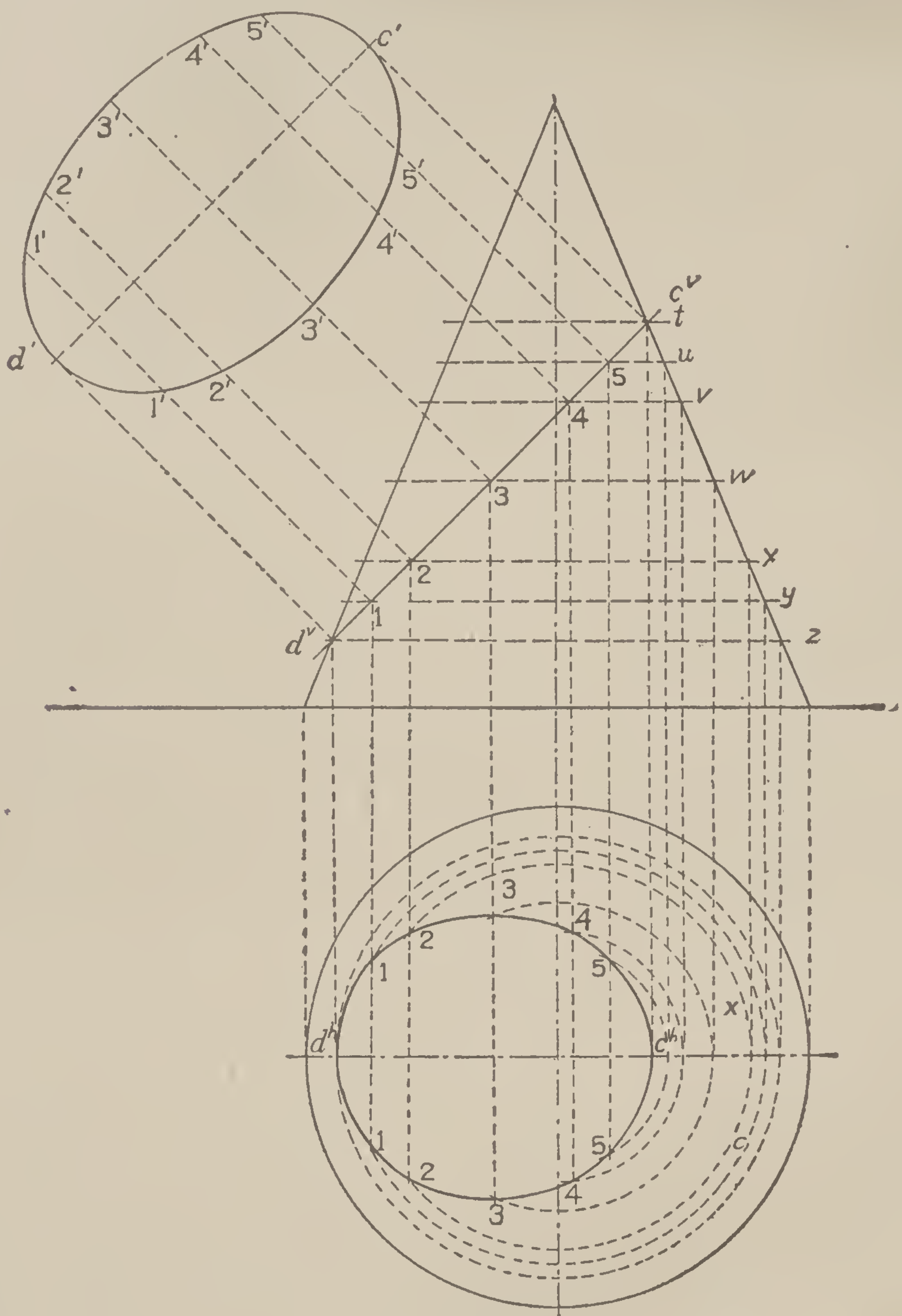


Fig. 31.

x y z etc., between points c^v and d^v. One of these planes, as w. should be taken through the center of c d. The points c and d must be points on the curve, since the plane cuts the two contour elements at these points. The horizontal projections of the contour elements will be found in a horizontal line passing through the center of the base; hence the horizontal projection of c and d will be found on this center line, and will be the extreme ends of the curve. Contour elements are those forming the outline.

The plane x cuts the surface of the cone in a circle, as it is parallel to the base, and the diameter of the circle is the distance between the points where x crosses the two contour elements. This circle, lettered x on the plan, has its center at the horizontal projection of the apex. The circle x and the curve cut by the plane are both on the surface of the cone, and their vertical projections intersect at the point 2. Also the circle x and the curve must cross twice, once on the front of the cone and once on the back. Point 2 then represents two points which are shown in plan directly beneath on the circle x, and are points on the required intersection. Planes y and z, and as many more as may be necessary to determine the curve accurately, are used in the same way. The curve found is an ellipse. The student will readily see that the true size of this ellipse is not shown in the plan, for the plane containing the curve is not parallel to the horizontal.

In order to find the **actual size** of the ellipse, it is necessary to place its plane in a position parallel either to the vertical or to the horizontal. The actual length of the long diameter of the ellipse must be shown in elevation, $c^v\, d^v$, because the line is parallel to the vertical plane. The plane of the ellipse then may be revolved about $c^v\, d^v$ as an axis until it becomes parallel to V, when its true size will be shown. For the sake of clearness of construction, $c^v\, d^v$ is imagined moved over to the position $c'\, d'$, parallel to $c^v\, d^v$. The lines 1—1, 2—2, 3—3 on the plan show the true width of the ellipse, as these lines are parallel to H, but are projected closer together than their actual distances. In elevation these lines are shown as the points 1, 2, 3. at their true distance apart. Hence if the ellipse is revolved around its axis $c^v\, d^v$, the distances 1—1, 2—2, 3—3 will appear perpendicular to $c^v\, d^v$, and the true size of the figure be shown. This construction is made on the left, where $1'$—$1'$, $2'$—$2'$ and $3'$—$3'$ are equal in length to 1—1, 2—2, 3—3 on the plan.

In Fig. 32 a plane cuts a cylinder obliquely. This is a simpler case, as the horizontal projection of the curve coincides with the base of the cylinder. To obtain the true size of the section, which is an ellipse, any number of points are assumed on the plan and projected up on the cutting plane, at 1, 2, 3, etc.

The lines drawn through these points perpendicular to 1 7 are made equal in length to the corresponding distances 2′—2′, 3′—3′ etc., on the plan, because 2′—2′ is the true width of curve at 2.

If a cone is intersected by a plane which is parallel to only one of the elements, as in Fig. 33, the resulting curve is the parabola, the construction of which is exactly similar to that for the ellipse as given in Fig. 31. If the intersecting plane is parallel to more than one element, or is parallel to the axis of the cone, a hyperbola is produced.

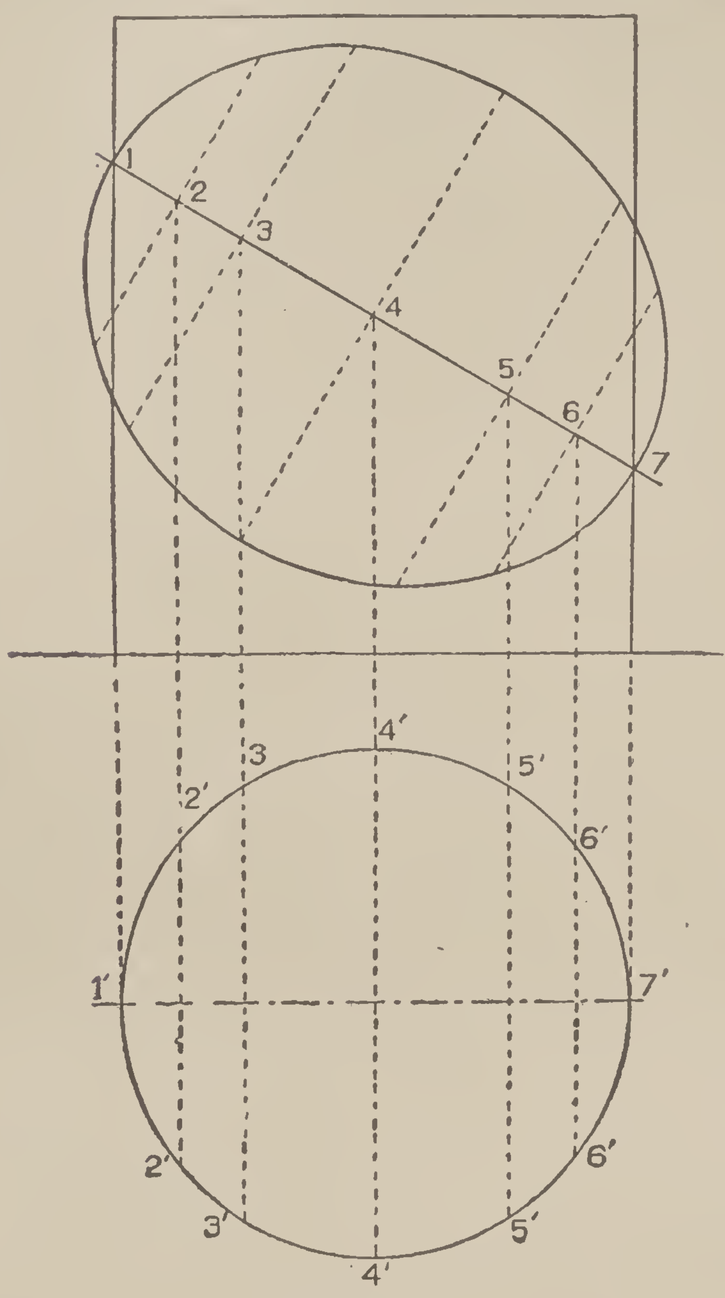


Fig. 32.

In Fig. 34, the vertical plane A is parallel to the axis of the cone. In this instance the curve when found will appear in its true size, as plane A is parallel to the vertical. Observe that the highest point of the curve is found by drawing the circle X on the plan tangent to the given plane. One of the points where this circle crosses the diameter is projected up to the contour element of the cone, and the horizontal plane X drawn. Intermediate planes Y, Z, etc., are chosen, and corresponding circles drawn in plan. The points where these circles are crossed by the plane A are points on the curve, and these points are projected up to the elevation on the planes Y, Z, etc.

DEVELOPMENTS.

The development of a surface is the true size and shape of the surface extended or spread out on a plane. If the surface to be developed is of such a character that it may be flattened out

without tearing or folding, we obtain an exact development, as in case of a cone or cylinder, prism or pyramid. If this cannot be done, as with the sphere, the development is only approximate.

In order to find the development of the rectangular prism in Fig 35, the back face, 1 2 7 6, is supposed to be placed in contact

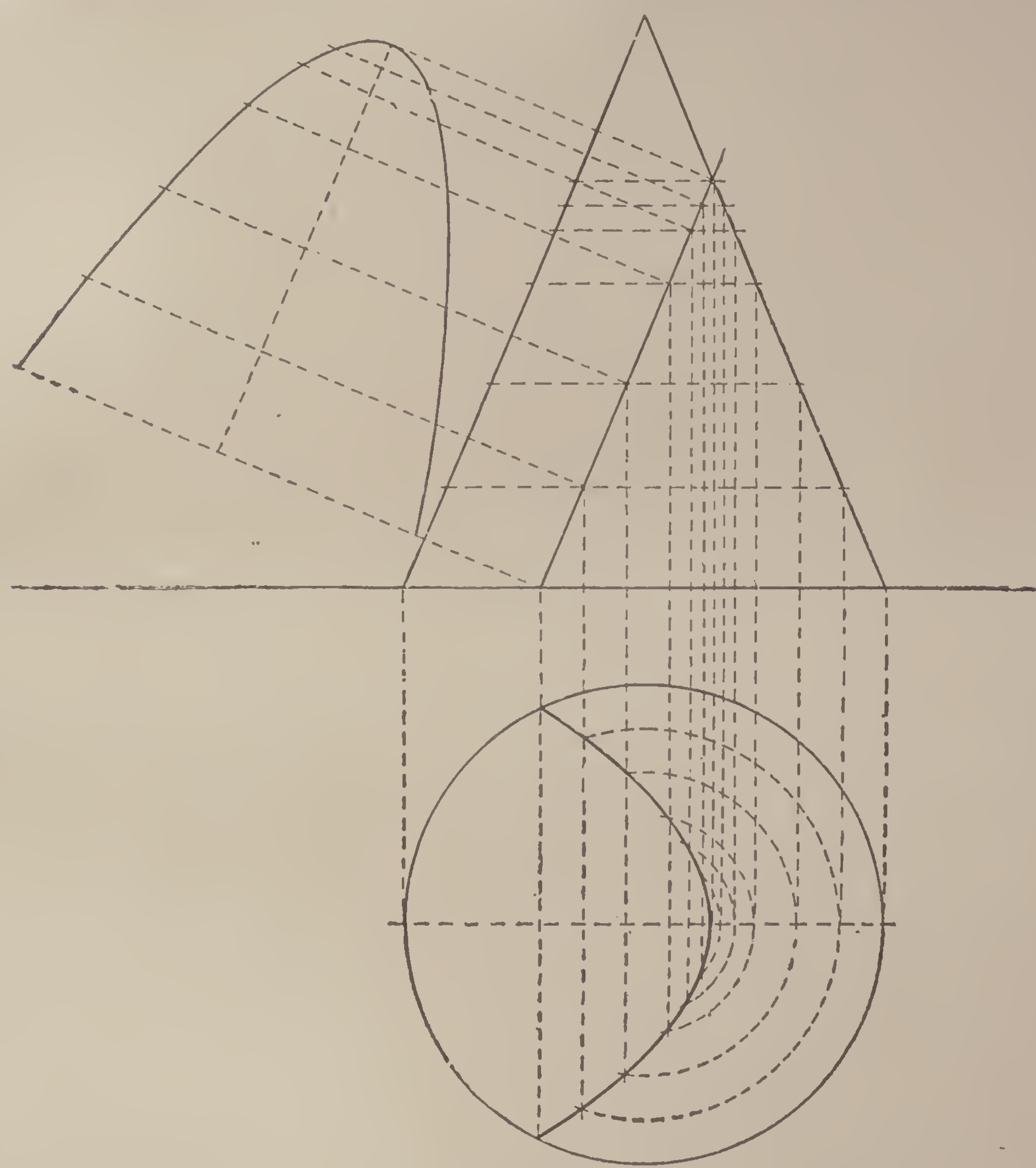


Fig. 33.

with some plane, then the prism turned on the edge 2 7 until the side 2 3 8 7 is in contact with the same plane, then this continued until all four faces have been placed on the same plane. The rectangles 1 4 3 2 and 6 7 8 5 are for the top and bottom respectively. The development then is the exact size and shape of a covering for the prism. If a rectangular hole is cut through the prism, the openings in the front and back faces will be shown in the development in the centers of the two broad faces.

The development of a right prism, then, consists of as many

rectangles joined together as the prism has sides, these rectangles being the exact size of the faces of the prism, and in addition two polygons the exact size of the bases. It will be found helpful in developing a solid to number or letter all of the corners on the projections, then designate each face when developed in the same way as in the figure.

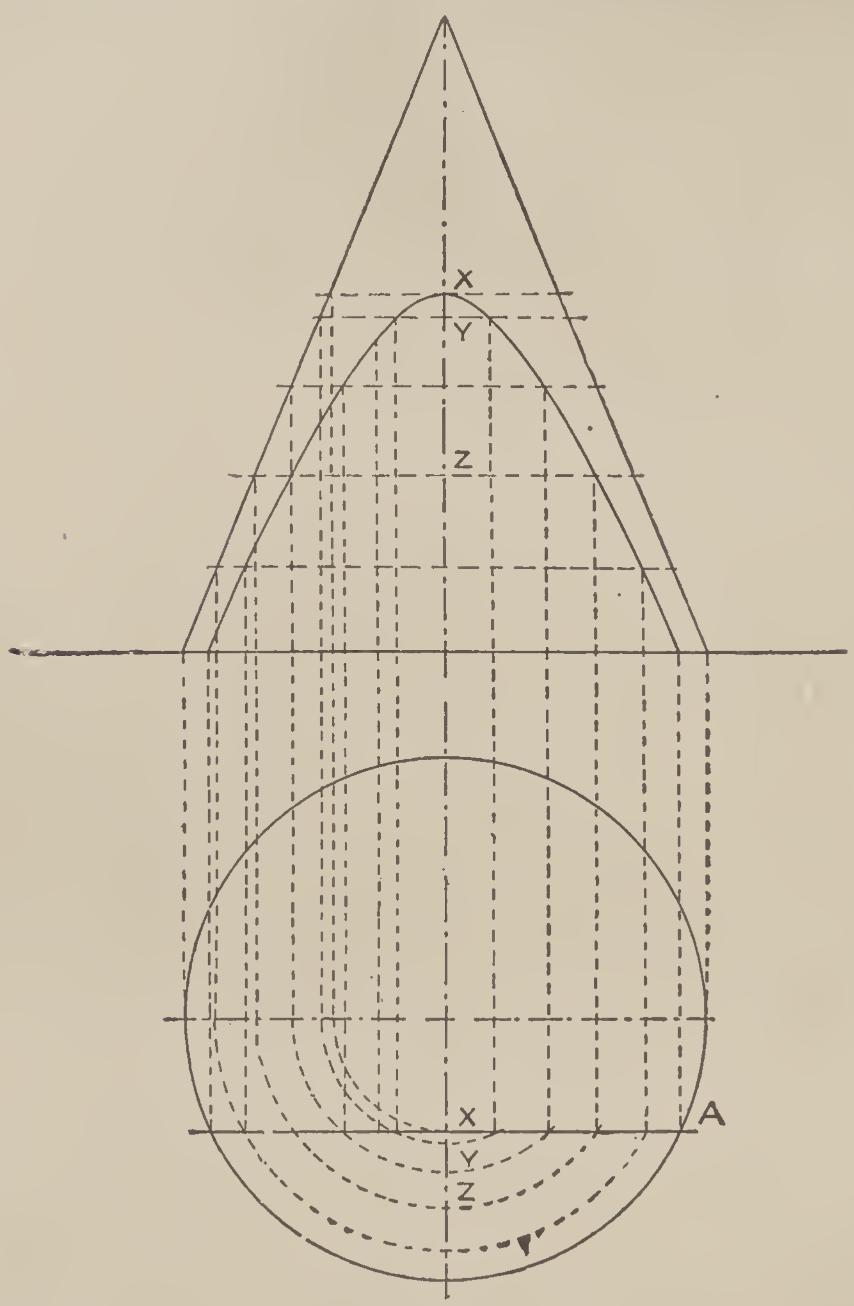


Fig. 34.

If a cone be placed on its side on a plane surface, one element will rest on the surface. If now the cone be rolled on the plane, the vertex remaining stationary, until the same element is in contact again, the space rolled over will represent the development of the convex surface of the cone. A, Fig. 36, is a cone cut by a plane parallel to the base. In B, let the vertex of the cone be placed at V, and one element of the cone coincide with V A I. The length of this element is taken from the elevation A, of either contour element. All of the elements of the cone are of the same length, so when the cone is rolled each point of the base as it touches the plane will be at the same distance from the vertex. From this it follows that the development of the base will be the arc of a circle of radius equal to the length of an element. To find the length of this arc which is equal to the distance around the base, divide the plan of the circumference of the base into any number of equal parts, as twelve, then

with the length of one of these parts as radius, lay off twelve spaces, 1....13, join 1 and 13 with V, and the sector is the development of the cone from vertex to base. To represent on the development

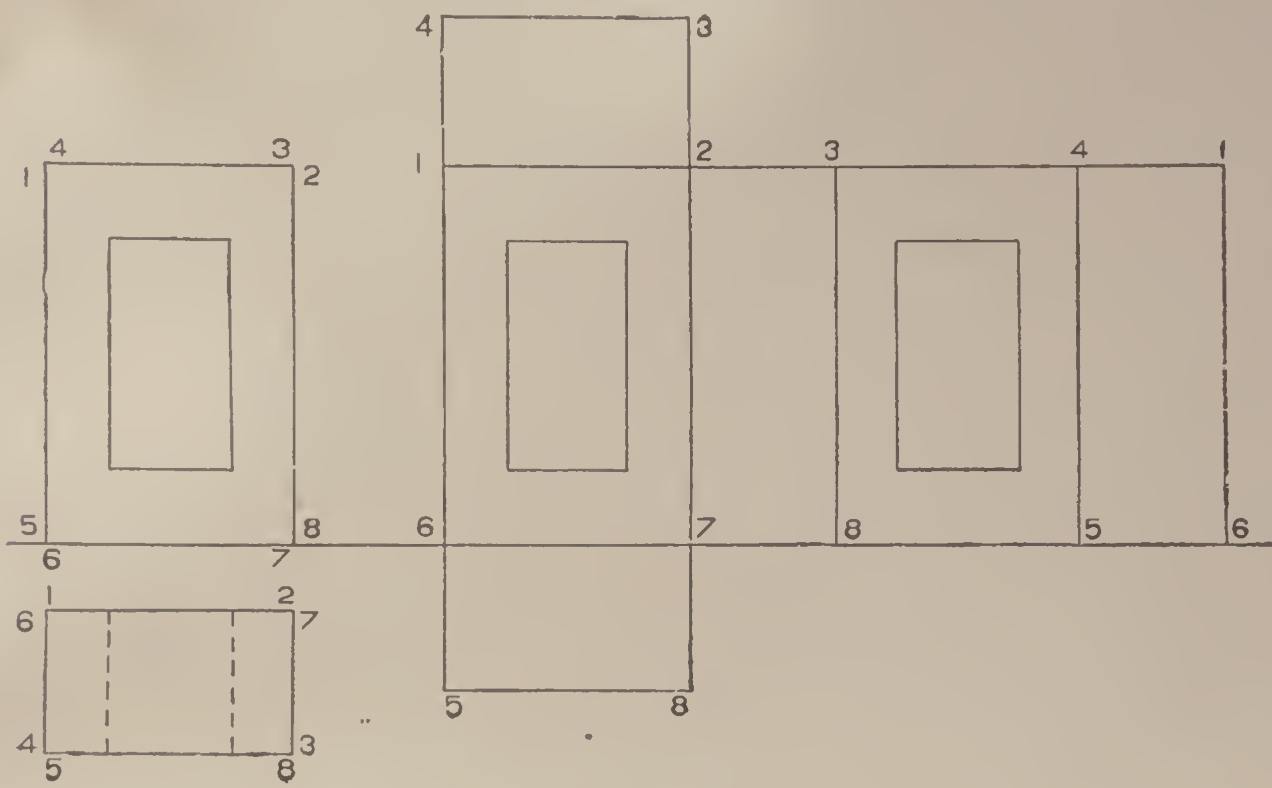


Fig. 35.

the circle cut by the section plane, take as radius the length of the element from the vertex to D, and with V as center describe

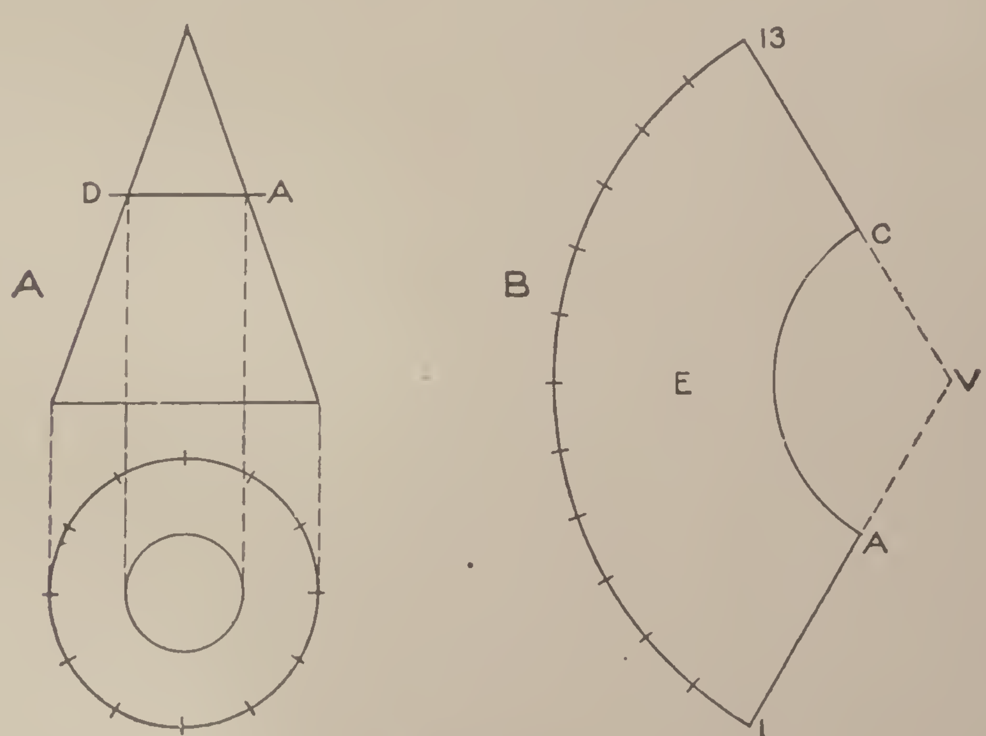


Fig. 36.

an arc. The development of the frustum of the cone will be the portion of the circular ring. This of course does not include the

development of the bases, which would be simply two circles the same sizes as shown in plan.

A and B, Fig. 37, represent the plan and elevation of a regular triangular pyramid and its development. If face C is placed on the plane its true size will be shown at C in the development. The true length of the base of triangle C is shown in the plan. The slanting edges, however, not being parallel to the vertical, are not shown in elevation in their true length. It becomes necessary then, to find the true length of one of these edges as shown in Fig. 6, after which the triangle may be drawn in its full size at C in the development. As the pyramid is regular, three equal triangles as shown developed at C, D and E, together with the base F, constitute the development.

If a right circular cylinder is to be developed, or rolled upon a plane, the elements, being parallel, will appear as parallel lines,

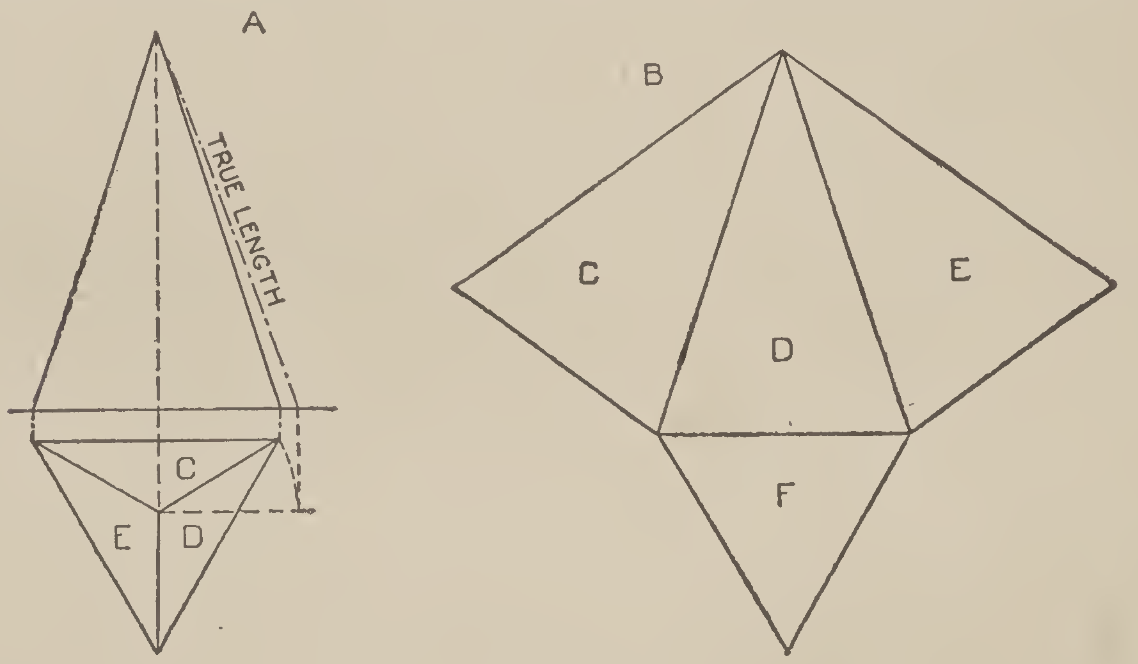


Fig. 37.

and the base, being perpendicular to the elements, will develop as a straight line perpendicular to the elements. The width of the development will be the distance around the cylinder, or the circumference of the base. The base of the cylinder in Fig. 38, is divided into twelve equal parts, 1 2 3, etc. Commencing at point 1 on the development these twelve equal spaces are laid along the straight line, giving the development of the base of the cylinder, and the total width. To find the development of the curve cut by the oblique plane, draw in elevation the elements corresponding to the various divisions of the base, and note the points

where they intersect the oblique plane. As we roll the cylinder beginning at point 1, the successive elements 1, 12, 11, etc., will appear at equal distances apart, and equal in length to the lengths of the same elements in elevation. Thus point number 10 on the development of the curve is found by projecting horizontally across from 10 in elevation. It will be seen that the curve is symmetrical, the half on the left of 7 being similar to that on the right. The development of any curve whatever on the surface of the cylinder may be found in the same manner.

The principle of cylinder development is used in laying out elbow joints, pipe ends cut off obliquely, etc. In Fig. 39 is shown plan and elevation of a three-piece elbow and collar, and develop-

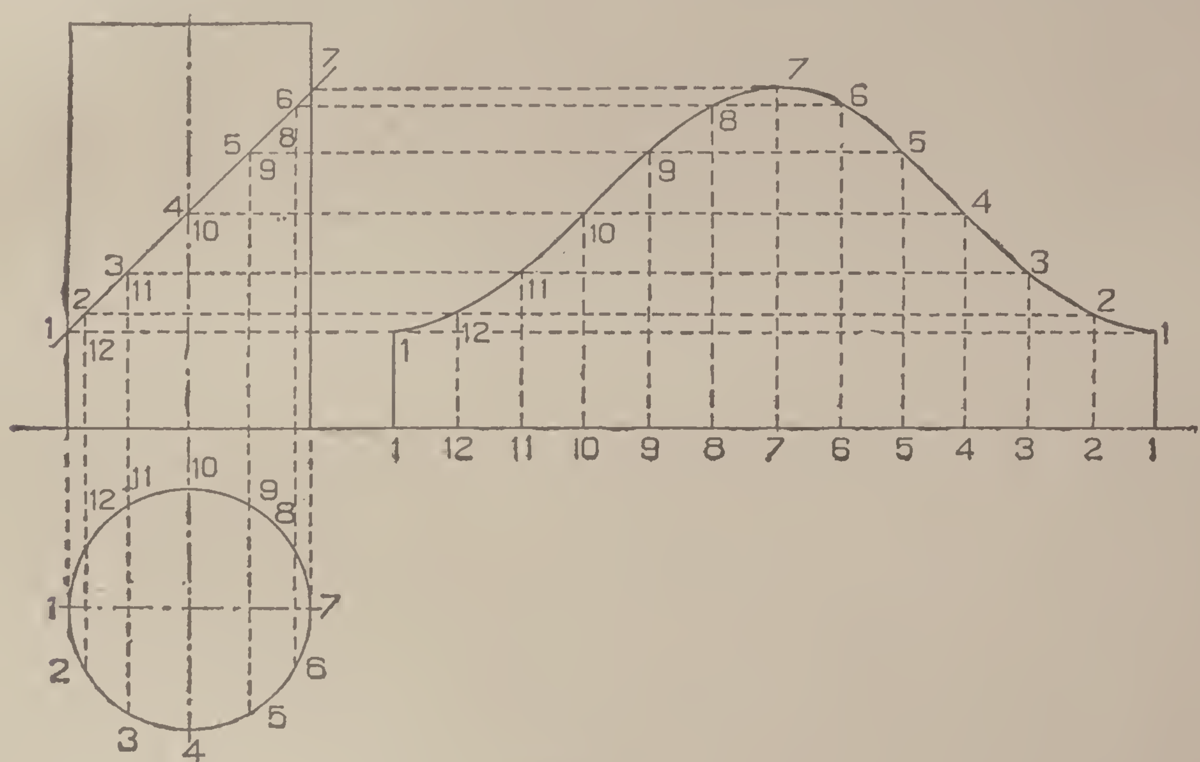


Fig. 38.

ments of the four pieces. In order to construct the various parts making up the joint, it is necessary to know what shape and size must be marked out on the flat sheet metal so that when cut out and rolled up the three pieces will form cylinders with the ends fitting together as required. Knowing the kind of elbow desired, we first draw the plan and elevation, and from these make the developments. Let the lengths of the three pieces A, B and C be the same on the upper outside contour of the elbow, the piece B at an angle of 45°; the joint between A and B bisects the angle between the two lengths, and in the same way the joint between B and C. The lengths A and C will then be the same,

and one pattern will answer for both. The development of A is made exactly as just explained for Fig. 38, and this is also the development of C.

It should be borne in mind that in developing a cylinder we must always have a base at right angles to the elements, and if the cylinder as given does not have such a base, it becomes necessary to cut the cylinder by a plane perpendicular to the elements, and use the intersection as a base. This point must be clearly understood in order to proceed intelligently. A section at right angles to the elements is the only section which will unroll in a

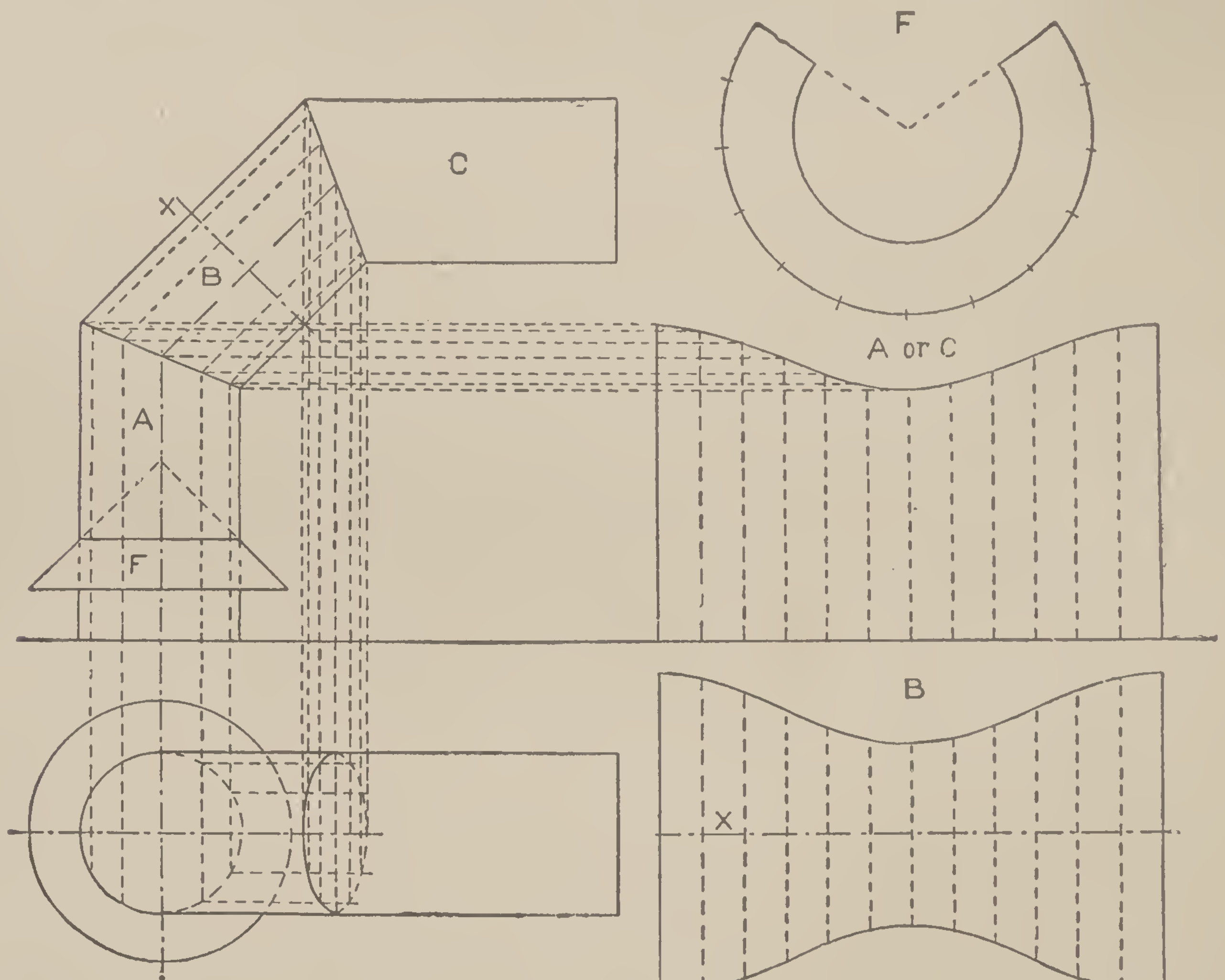


Fig. 39.

straight line, and is therefore the section from which we must work in developing other sections. As B has neither end at right angles to its length, the plane X is drawn at the middle and perpendicular to the length. B is the same diameter pipe as C and A, so the section cut by X will be a circle of the same diameter as the base of A, and its development is shown at X.

From the points where the elements drawn on the elevation of A meet the joint between A and B, elements are drawn on B,

which are equally spaced around B the same as on A. The spaces then laid off along X are the same as given on the plan of A. Commencing with the left-hand element in B, the length of the upper element between X and the top corner of the elbow is laid off above X, giving the first point in the development of the end of B fitting with C. The lengths of the other elements in the elevation of B are measured in the same way and laid off from X. The development of the other end of the piece B is laid off below X, using the same distances, since X is half way between the ends. The development of the collar is simply the development of the frustum of a cone, which has already been explained, Fig. 36. The joint between B and C is shown in plan as an ellipse, the construction of which the student should be able to understand from a study of the figure.

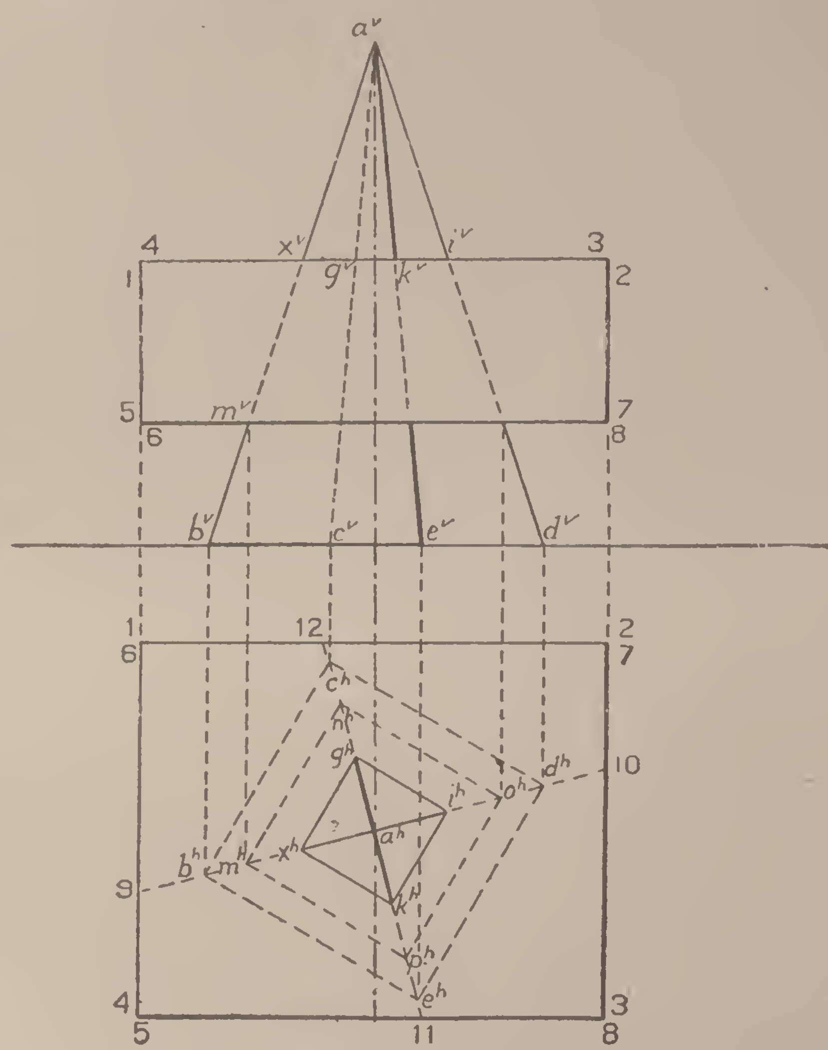


Fig. 40.

The intersection of a rectangular prism and pyramid is shown in Fig. 40. The base $b\ c\ d\ e$ of the pyramid is shown dotted in plan, as it is hidden by the prism. All four edges of the pyramid pass through the top of the prism, 1, 2, 3, 4. As the top of the prism is a horizontal plane, the edges of the pyramid are shown passing through the top in elevation at $x^v\ g^v\ k^v\ i^v$. These four points might be projected to the plan on the four edges of the pyramid; but it is unnecessary to project more than one, since the general principle applies here that if a cone, pyramid, prism or cylinder be cut by a plane parallel to the base, the section is a figure parallel and similar to the base. The one point x^v is therefore projected down to $a\ b$ in plan, giving x^h, and with this as

one corner, the square $x^h g^h i^h k^h$ is drawn, its sides parallel to the edges of the base. This square is the intersection of the pyramid with the top of the prism.

The intersection of the pyramid with the bottom of the prism is found in like manner, by taking the point where one edge of the pyramid as $a\ b$ passes through the bottom of the prism shown in elevation as point m^v, projecting down to m^h on $a^h\ b^h$, and drawing the square $m^h n^h o^h p^h$ parallel to the base of the pyramid. These two squares constitute the entire intersection of the two solids, the pyramid going through the bottom and coming out at the top of the prism. As much of the slanting edges of the

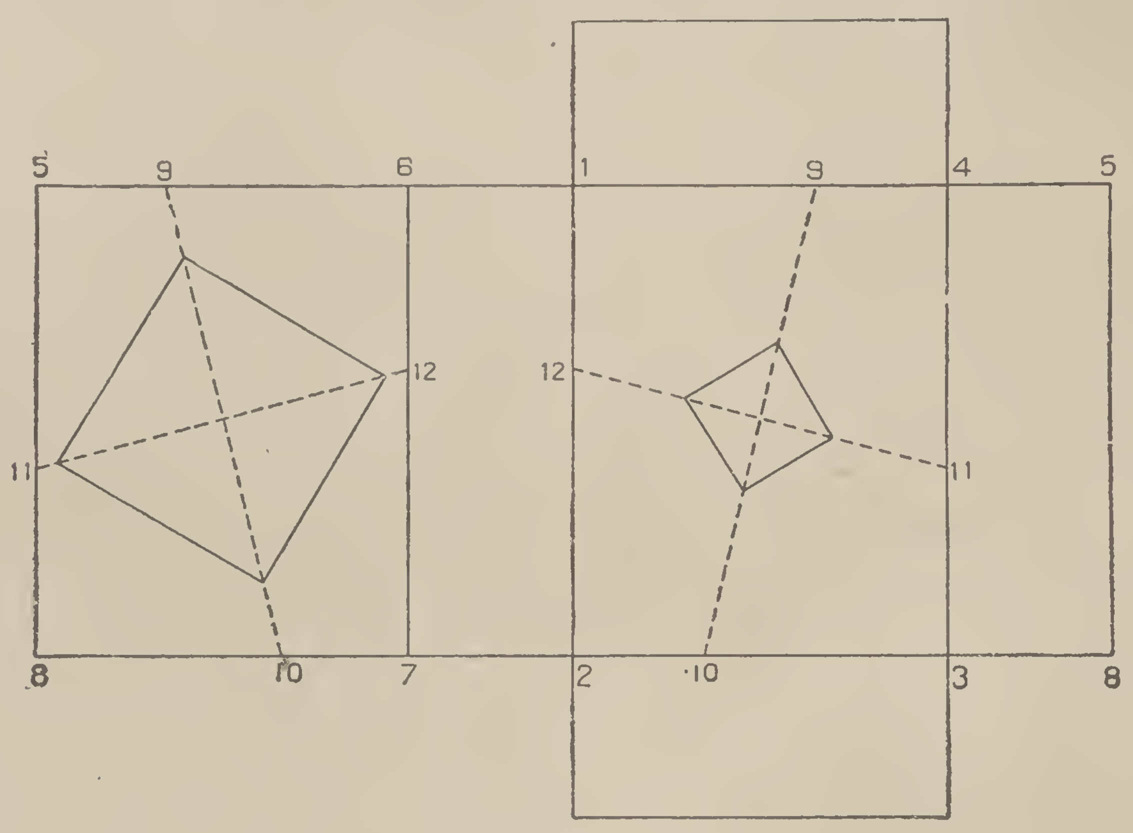


Fig. 41.

pyramid as are above the prism will be seen in plan, appearing as the diagonals of the small square, and the rest of the pyramid, being below the top surface of the prism, will be dotted in plan.

Fig. 41 is the development of the rectangular prism, showing the openings in the top and bottom surfaces through which the pyramid passed. The development of the top and bottom, back and front faces will be four rectangles joined together, the same sizes as the respective faces. Commencing with the bottom face 5 6 7 8, next would come the back face 6 1 2 7, then the top, etc. The rectangles at the ends of the top face 1 2 3 4 are the ends of the prism. These might have been joined on any other

face as well. Now find the development of the square in the bottom 5 6 7 8. As the size will be the same as in projection, it only remains to determine its position. This position, however, will have the same relation to the sides of the rectangle as in the plan. The center of the square in this case is in the center of the face. To transfer the diagonals of the square to the development, extend them in plan to intersect the edges of the prism in points 9, 10, 11 and 12. Take the distance from 5 to 9 along the edge 5 6, and lay it on the development from 5 along 5 6, giving point 9. Point 10 located in the same way and connected with 9, gives the position of one diagonal. The other diagonal is obtained in a similar way, then the square constructed on these diagonals. The same method is used for locating the small square on the top face.

If the intersection of a cylinder and prism is to be found, we may either obtain the points where elements of the cylinder pierce the prism, or where edges and lines parallel to edges on the surface of the prism cut the cylinder.

A series of parallel planes may also be taken cutting curves from the cylinder and straight lines from the prism; the intersections give points on the intersection of the two solids.

Fig. 42 represents a triangular prism intersecting a cylinder. The axis of the prism is parallel to V and inclined to H. Starting with the size and shape of the base, this is laid off at a_1 b^h c^h, and the altitude of the triangle taken and laid off at a^v c^v in elevation, making right angles with the inclination of the axis to H. The plan of the prism is then constructed. To find the intersection of the two solids, lines are drawn on the surface of the prism parallel to the length and the points where these lines and the edges pierce the cylinder are obtained and joined, giving the curve.

The top edge of the prism goes into the top of the cylinder. This point will be shown in elevation, since the top of the cylinder is a plane parallel to H and perpendicular to V, and therefore projected on V as a straight line. The upper edge, then, is found to pass into the top of the cylinder at point *o*, o^v and o^h. The intersection of the two upper faces of the prism with the top of the cylinder will be straight lines drawn from point *o* and will be shown in plan. If we can find where another line of the surface *o a b* 14 pierces the upper base of the cylinder, this point joined

with o will determine the intersection of this face with the top of the cylinder. A surface may always be produced, if necessary, to find an intersection.

Edge $a\ b$ pierces the plane of the top of the cylinder at point

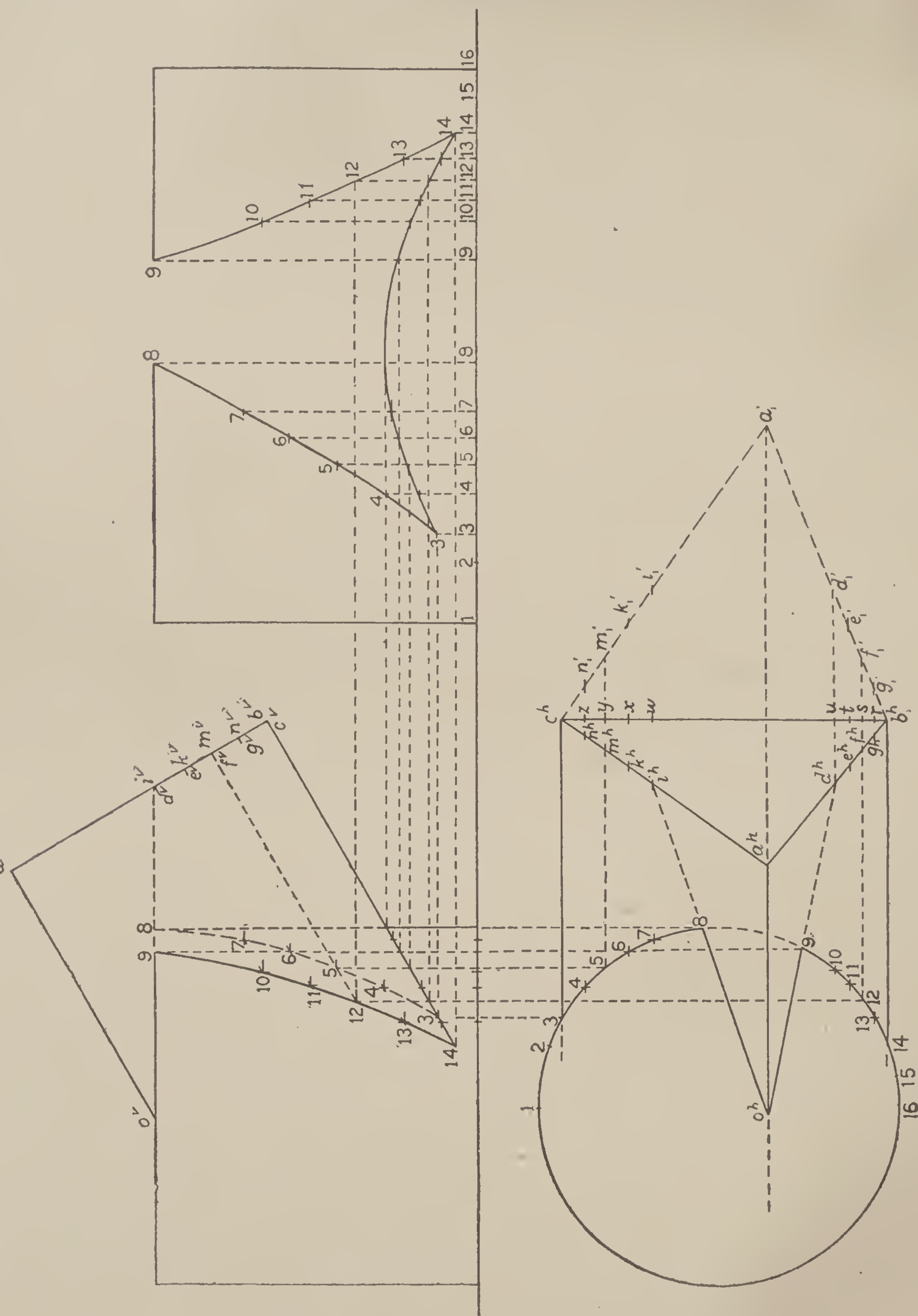


Fig. 43.

Fig. 42.

d, seen in elevation; therefore the line joining this point with o is the intersection of one upper face of the prism with the upper

base of the cylinder. The only part of this line needed, of course, is within the actual limits of the base, that is o 9. The intersection o 8 of the other top face is found by the same method. On the convex surface of the cylinder there will be three curves, one for each face of the prism. Points 8 and 9 on the upper base of the cylinder, will be where the curves for the two upper faces will begin. The point d is found on the revolved position of the base at d_1, and $d_1\ b$ is divided into the equal parts $d_1 - e_1$, $e_1 - f_1$, etc., which revolve back to d^h, e^h, f^h and g^h. The divisions are made equal merely for convenience in developing. The vertical projections of d, e, etc., are found on the vertical projection of $a\ b$, directly above d^h, e^h, etc., or may be found by taking from the revolved position of the base, the perpendiculars from $d_1\ e_1$ etc., to $c^h\ b^h$ and laying them off in elevation from b^v along $b^v\ a^v$. Lines such as f 12, m 5, etc., parallel to $a\ o$ are drawn in plan and elevation. Points $i^h\ k^h\ m^h\ n^h$ are taken directly behind $d^h\ e^h\ f^h\ g^h$ hence their vertical projections coincide. Points $n_1\ m_1\ k_1$ and i_1 are formed by projecting across from $n^h\ m^h\ k^h$ and i^h.

The convex surface of the cylinder is perpendicular to H, so the points where the lines on the prism pierce it will be projected on plan as the points where these lines cross the circle, 14, 13, 12, 11.......3. The vertical projections of these points are found on the corresponding lines in elevation, and the curves drawn through. The curve 3, 4....8 must be dotted, as it is on the back of the cylinder. The under face of the prism, which ends with the line $b\ c$, is perpendicular to the vertical plane, so the curve of intersection will be projected on V as a straight line. Point 14 is one end of this curve. 3 the other end, and the curve is projected in elevation as the straight line from 14 to the point where the lower edge of the prism crosses the contour element of the cylinder.

Fig. 43 gives the development of the right-hand half of the cylinder, beginning with number 1. As previously explained, the distance between the elements is shown in the plan, as 1—2, 2—3, 3—4 and so on. These spaces are laid off in the development along a straight line representing the development of the base, and from these points the elements are drawn perpendicularly.

The lengths of the elements in the development from the base to the curve are exactly the same as on the elevation, as the

elevation gives the true lengths. If then the development of the base is laid off along the same straight line as the vertical projection of the base, the points in elevation may be projected across with the T-square to the corresponding elements in the development. The points on the curve cut by the under face of the prism are on the same elements as the other curves, and their vertical projections are on the under edge of the prism, hence these points are projected across for the development of the lower curve.

In Fig. 44 is given the development of the prism from the right-hand end as far as the intersection with the cylinder, begin-

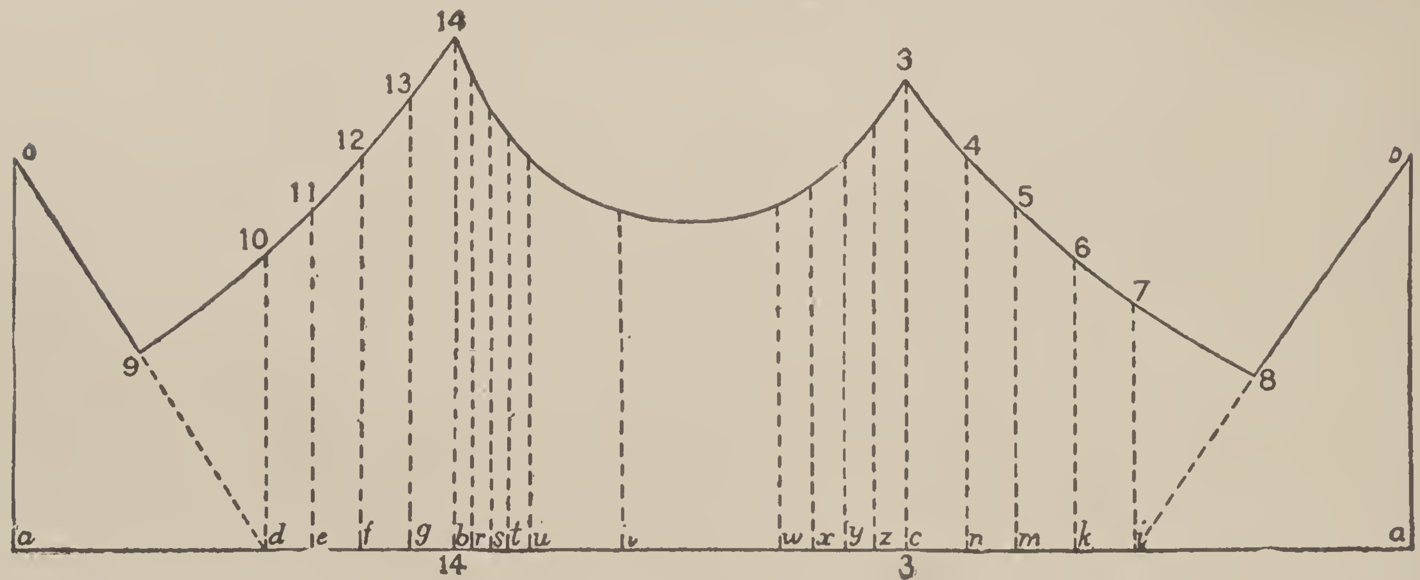


Fig. 44.

ning at the left with the top edge *a o*, the straight line *a b c a* being the development of the base. As this must be the actual distance around the base, the length is taken from the true size of the base, $a_1 b^h c^h$. The parallel lines drawn on the surfaces of the prism must appear on the development their true distances apart, hence the distances $a_1 d_1$, $d_1 e_1$, etc., are made equal to *a d*, *d e*, etc. on the development. The actual distances between the parallel lines on the bottom face of the prism are shown along the edge of the base, $b^h c^h$. Perpendicular lines are drawn from the points of division on the development.

The position of the developed curve is found by laying off the true lengths on the perpendiculars. These true lengths (of the parallel lines) are not shown in plan, as the lines are not parallel to the horizontal plane, but are found in elevation. The length *oa* on the development is equal to $a^v o^v$, *d* 10 to d^v 10, and

so on for all the rest. Point 9 is found as follows: on the projections, the straight line from *o* to *d* passes through point 9, and the true distance from *o* to 9 is shown in plan. All that is necessary, then, is to connect *o* and *d* on the development, and lay off from *o* the distance o^h9. Number 8 is found in the same way.

ISOMETRIC PROJECTION.

Heretofore an object has been represented by two or more projections. Another system, called **isometrical drawing,** is used to show in one view the three dimensions of an object, length (or height), breadth, and thickness. An isometrical drawing of an object, as a cube, is called for brevity the "isometric" of the cube.

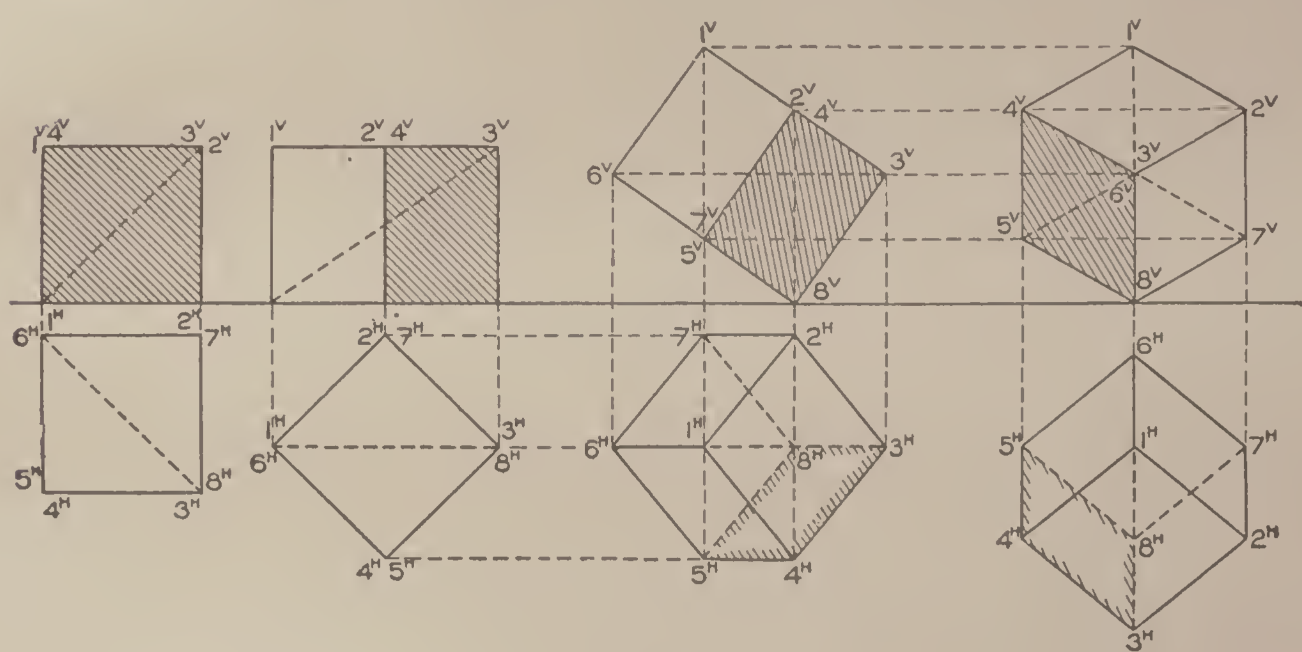


Fig. 45.

To obtain a view which shows the three dimensions in such a way that measurements can be taken from them, draw the cube in the simple position shown at the left of Fig. 45, in which it rests on H with two faces parallel to V; the diagonal from the front upper right-hand corner to the back lower left-hand corner is indicated by the dotted line. Swing the cube around until the diagonal is parallel with V as shown in the second position. Here the front face is at the right. In the third position the lower end of the diagonal has been raised so that it is parallel to H, becoming thus parallel to both planes. The plan is found by the principles of projection, from the elevation and the preceding plan. The front face is now the lower of the two faces shown in the elevation. From this position the cube is swung around, using the corner

resting on the H as a pivot, until the diagonal is perpendicular to V but still parallel to H. The plan remains the same, except as regards position; while the elevation, obtained by projecting across from the previous elevation, gives the isometrical projection of the cube. The front face is now at the left.

In the last position, as one diagonal is perpendicular to V, it follows that all the faces of the cube make equal angles with V, hence are projected on that plane as equal parallelograms. For the same reason all the edges of the cube are projected in elevation in equal lengths, but, being inclined to V, appear shorter than they actually are on the object. Since they are all equally foreshortened and since a drawing may be made at any scale, it is customary to make all the isometrical lines of a drawing full length. This will give the same proportions, and is much the simplest method. Herein lies the distinction between an isometrical projection and an isometric drawing.

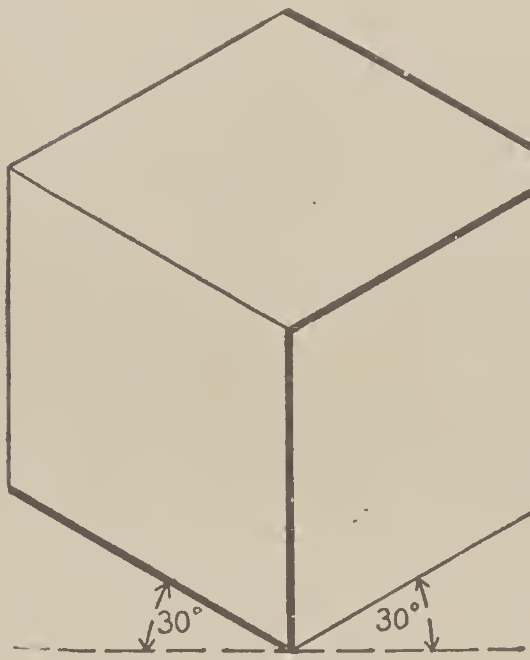


Fig. 46.

It will be noticed that the figure can be inscribed in a circle, and that the outline is a perfect hexagon. Hence the lines showing breadth and length are 30° lines, while those showing height are vertical.

Fig. 46 shows the isometric of a cube, 1 inch square. All of the edges are shown in their true length, hence all the surfaces appear of the same size. In the figure the edges of the base are inclined at 30° with a T-square line, but this is not always the case. For rectangular objects, such as prisms, cubes, etc., the base edges are at 30° only when the prism or cube is supposed to be in the simplest possible position. The cube in Fig. 46 is supposed to be in the position indicated by plan and elevation in Fig. 47, that is, standing on its base, with two faces parallel to the vertical plane.

If the isometric of the cube in the position of Fig. 48 were required, it could not be drawn with the base edges at 30°; neither

would these edges appear in their true lengths. It follows, then, that in isometrical drawing, true lengths appear only as 30° lines or as vertical lines. Edges or lines that in actual projection are either parallel to the ground line or perpendicular to V, are drawn in isometric as 30° lines, full length; and those that are actually vertical are made vertical in isometric, also full length.

In Fig. 45, lines such as the front vertical edges of the cube and the two base edges are called the three **isometric axes.** The isometric of objects in oblique positions, as in Fig. 48, can be con-

Fig. 47.

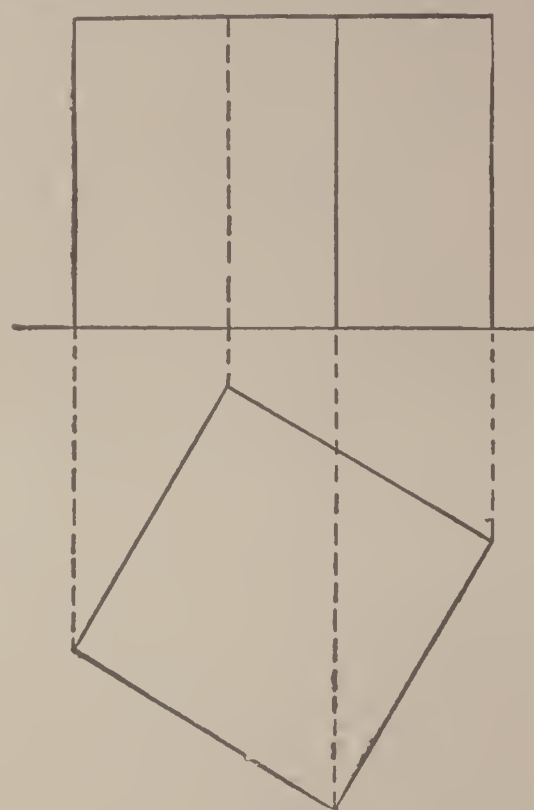


Fig. 48.

structed only by reference to their projections, by methods which will be explained later.

In isometric drawing small rectangular objects are more satisfactorily represented than large curved ones. In woodwork, mortises and joints and various parts of framing are well shown in isometric. This system is used also to give a kind of bird's-eye view of the mills or factories. It is also used in making sketches of small rectangular pieces of machinery, where it is desirable to give shape and dimensions in one view.

In isometric drawing the **direction of the ray of light** is parallel to that diagonal of a cube which runs from the upper left corner to the lower right corner, as 4^v-7^v in the last elevation of Fig. 45. This diagonal is at 30°; hence in isometrical drawing the direction of the light is at 30° downward to the right. From

this it follows that the top and two left-hand faces of the cube are light, the others dark. This explains the shade lines in Fig. 45.

In Fig. 45, the top end of the diagonal which is parallel to the ray of light in the first position is marked 4, and traced through to the last or isometrical projection, 4^v. It will be seen that face $3^v\ 4^v\ 5^v\ 8^v$ of the isometric projection is the front face of the cube in the first view; hence we may consider the left front face of the isometric cube as the front. This is not absolutely necessary, but by so doing the isometric shade edges are exactly the same as on the original projection.

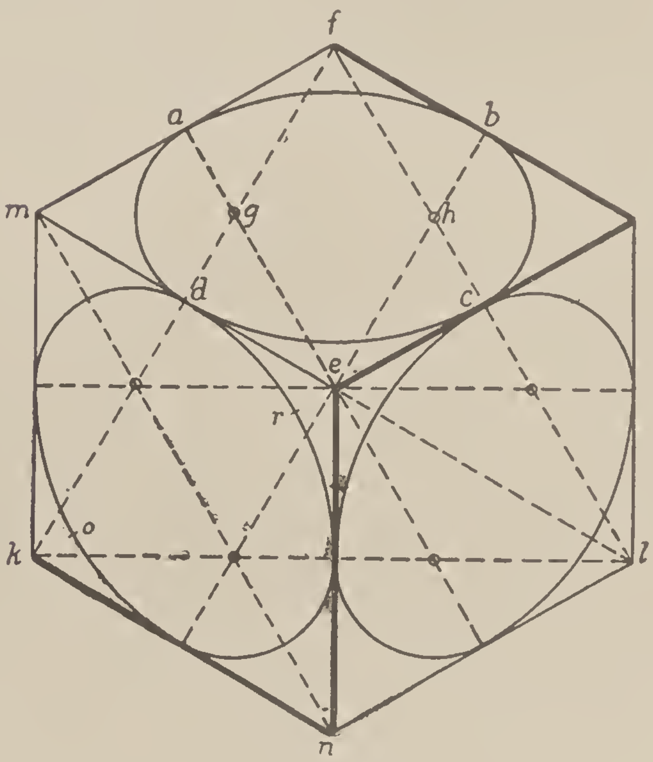


Fig. 49.

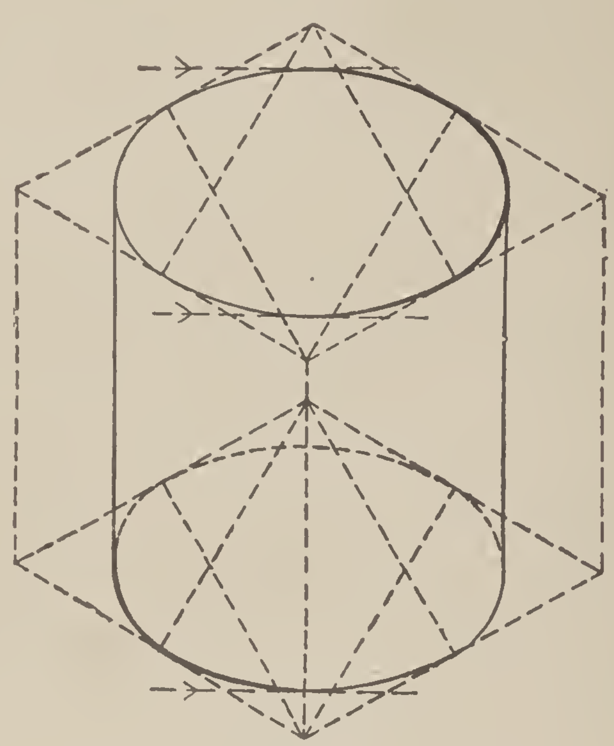


Fig. 50.

Fig. 49 shows a cube with circles inscribed in the top and two side faces. The isometric of a circle is an ellipse, the exact construction of which would necessitate finding a number of points; for this reason an approximate construction by arcs of circles is often made. In the method of Fig. 49, four centers are used. Considering the upper face of the cube, lines are drawn from the obtuse angles *f* and *e*, to the centers of the opposite sides.

The intersections of these lines give points *g* and *h*, which serve as centers for the ends of the ellipse. With center *g* and radius *g a*, the arc *a d* is drawn; and with *f* as center and radius *f d*, the arc *d c* is described, and the ellipse finished by using centers *h* and *e*. This construction is applied to all three faces.

Fig. 50 is the isometric of a cylinder standing on its base.

Notice that the shade line on the top begins and ends where T-square lines would be tangent to the curve, and similarly in the case of the part shown on the base. The explanation of the shade is very similar to that in projections. Given in projections a cylinder standing on its base, the plan is a circle, and the shade line is determined by applying the 45° triangle tangent to the circle. This is done because the 45° line is the projection of the ray of light on the plane of the base.

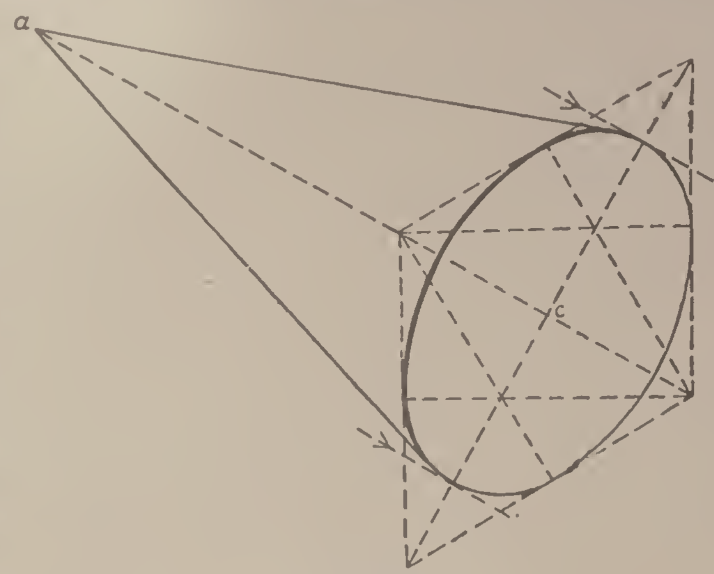


Fig. 51.

In Fig. 49, the diagonal *m l* may represent the ray of light and its projection on the base is seen to be *k l*, the diagonal of the base, a T-square line. Hence, for the cylinder of Fig. 50, apply tangent to the base and also to the top a line parallel to the projection of the ray of light on these planes, that is, a T-square line, and this will mark the beginning and ending of the shade line.

In Fig. 49 the projection of the ray of light diagonal *m l* on the right-hand face is *e l*, a 30° line; hence, in Fig. 51, where the base is similarly placed, apply the 30° triangle tangent as indicated, determining the shade line of the base. If the ellipse on the left-hand face of the cube were the base of a cone or cylinder extending backward to the right, the same principle would be used.

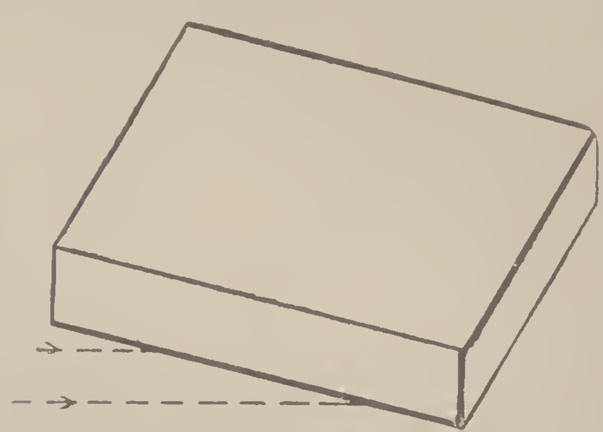


Fig. 52.

The projection of the cube diagonal *m l* on that face is *m n*, a 60° line; hence the 60° triangle would be used tangent to the base in this last supposed case, giving the ends of the shade line at points *o* and *r*. Figs. 52, 53 and 54 illustrate the same idea with respect to prisms, the direction of the projection of the ray of light on the plane of the base being used in each case to determine the light and dark faces and hence the shade lines.

In Fig. 52 a prism is represented standing on its base, so that the projection of the cube diagonal on the base (that is, a T-square line) is used to determine the light and dark faces as shown. The prism in Fig. 53 has for its base a trapezium. The projection of the ray of light on this end is parallel to the diagonal of the face; hence the 60° triangle applied parallel to this diagonal shows that faces *a c d b* and *a g h b* are light, while *c e f d* and *g e f h* are dark, hence the shade lines as shown.

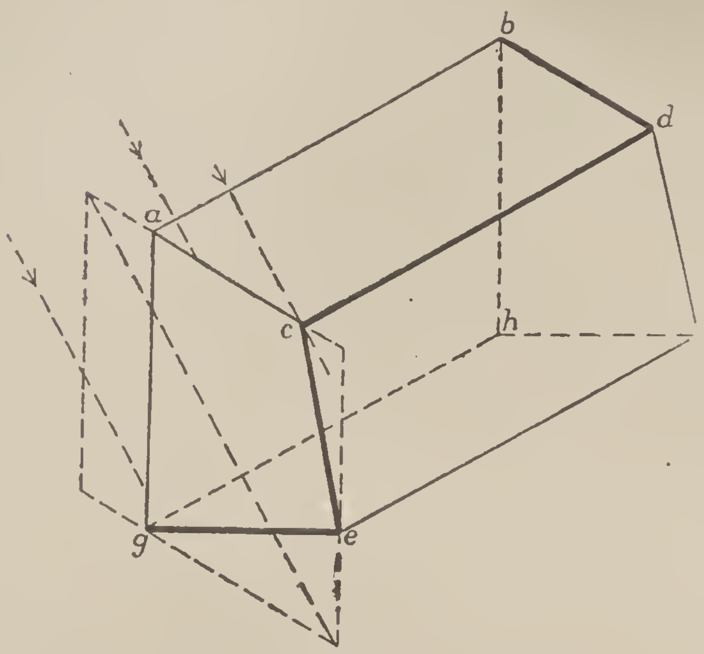


Fig. 53.

The application in Fig. 54 is the same, the only difference being in the position of the prism, and the consequent difference in the direction of the diagonal.

Fig. 55 represents a block with smaller blocks projecting from three faces.

Fig. 56 shows a framework of three pieces, two at right angles and a slanting brace. The horizontal piece is mortised into the upright, as indicated by the dotted lines. In Fig. 57 the isometric outline of a house is represented, showing a dormer window and a partial hip roof; *a b* is a hip rafter, *c d* a valley. Let the pitch of the main roof be shown at B, and let *m* be the middle point of the top of the end wall of the house. Then, by measuring vertically up a distance *m l* equal to the vertical height *a n* shown at B, a point on the line of the ridge will be found at *l*. Line *l i* is equal to *b h*, and *i h* is then drawn. Let the pitch of

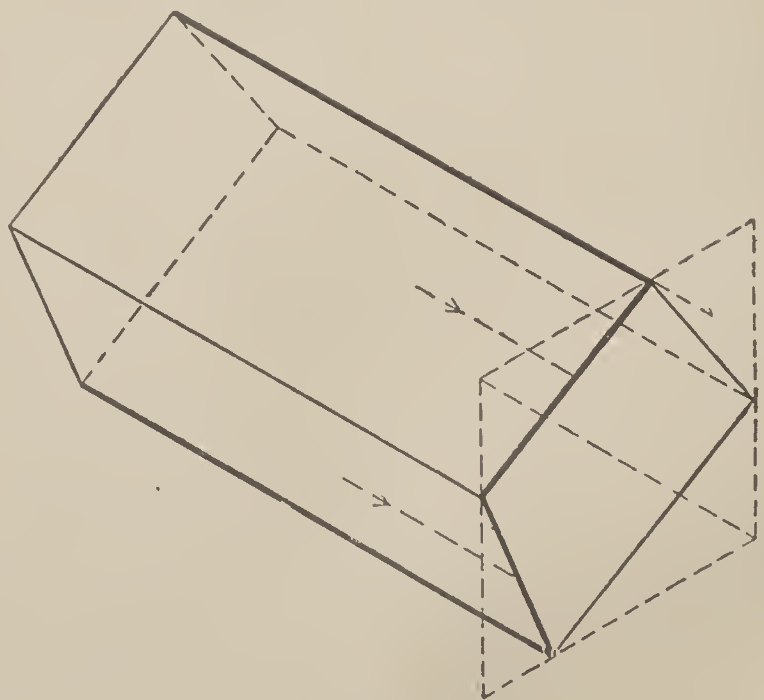
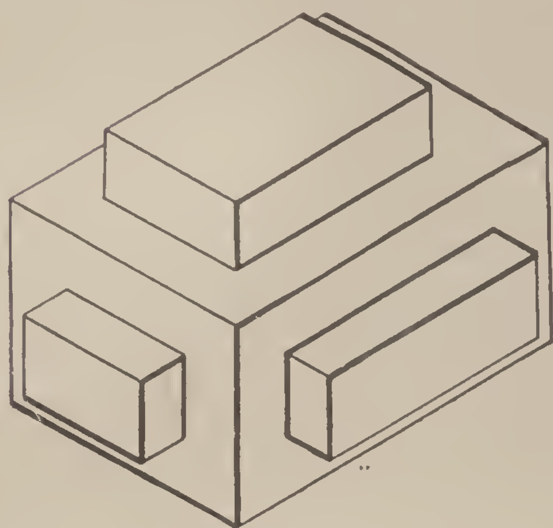


Fig. 54.

the end roof be given at A. This shows that the peak of the roof, or the end *a* of the ridge, will be back from the end wall a distance equal to the base of the triangle at A. Hence lay off from *l* this distance, giving point *a*, and join *a* with *b* and *x*.



Fig, 55.

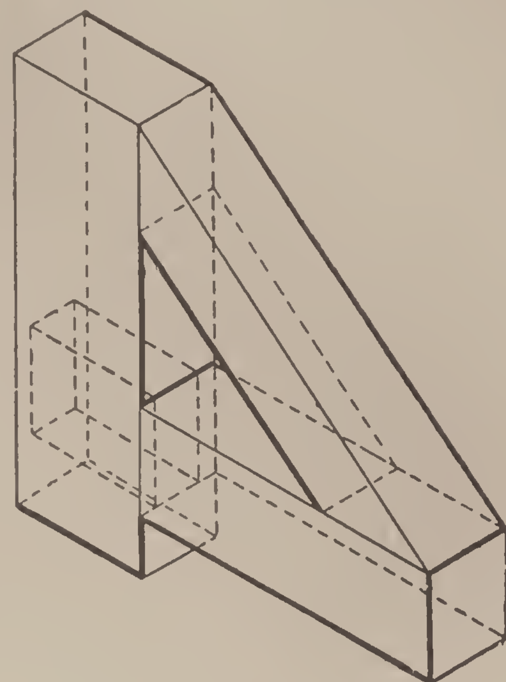


Fig. 56.

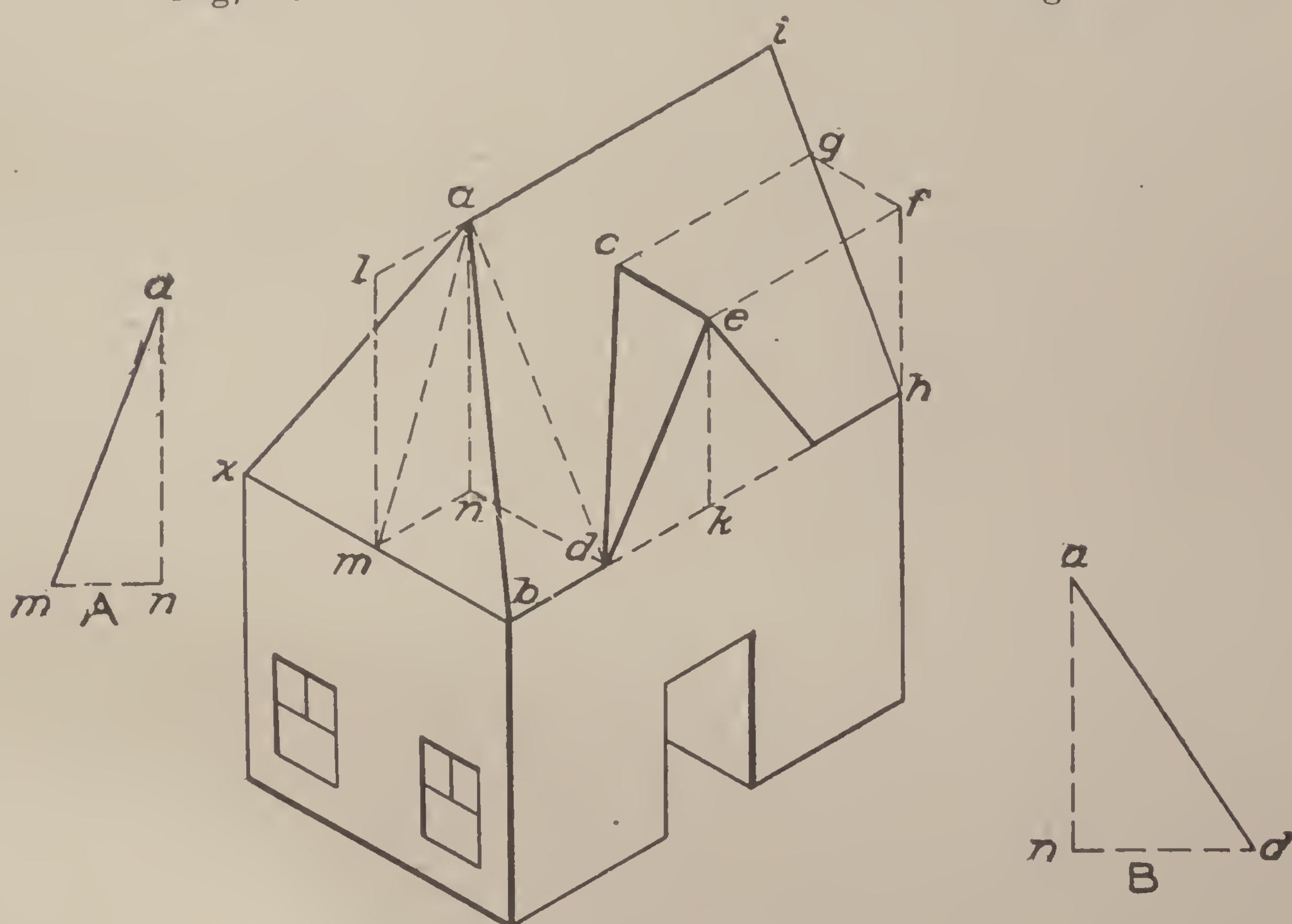


Fig. 57.

The height *k e* of the ridge of the dormer roof is known, and we must find where this ridge will meet the main roof. The ridge must be a 30° line as it runs parallel to the end wall of the house

and to the ground. Draw from e a line parallel to $b\ h$ to meet a vertical through h at f. This point is in the vertical plane of the end wall of the house, hence in the plane of $i\ h$. If now a 30° line be drawn from f parallel to $x\ b$, it will meet the roof of the house at g. The dormer ridge and $f\ g$ are in the same horizontal plane, hence will meet the roof at the same distance below the ridge $a\ i$. Therefore draw the 30° line $g\ c$, and connect c with d.

In Fig. 58 a box is shown with the cover opened through 150°.

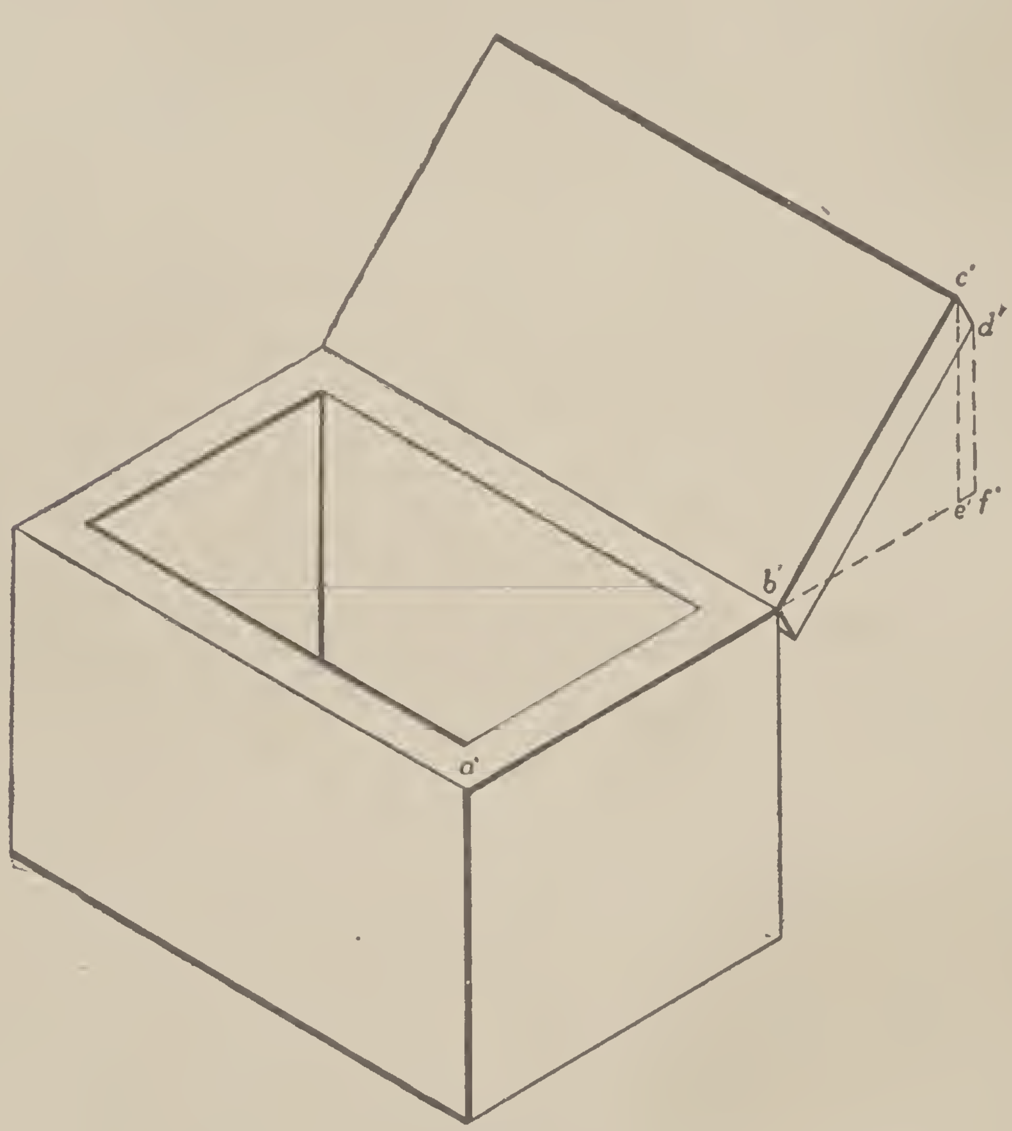


Fig. 58.

The right-hand edge of the bottom shows the width, the left-hand edge the length, and the vertical edge the height. The short edges of the cover are not isometric lines, hence are not shown in their true lengths; neither is the angle through which the cover is opened represented in its actual size.

The corners of the cover must then be determined by co-ordinates from an end view of the box and cover. As the end of the cover is in the same plane as the end of the box, the simple

end view as shown in Fig. 59 will be sufficient. Extend the top of the box to the right, and from c and d let fall perpendiculars or $a\,b$ produced, giving the points e and f. The point c may be located by means of the two distances or co-ordinates $b\,e$ and $e\,c$.

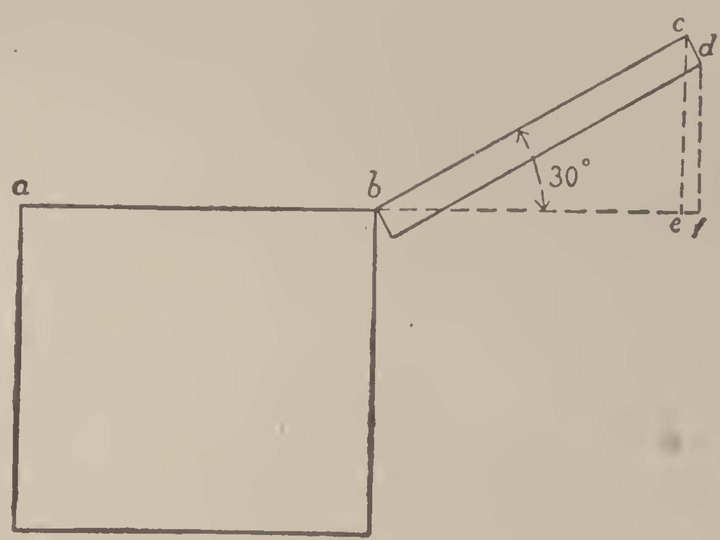


Fig. 59.

and these distances will appear in their true lengths in the isometric view. Hence produce $a'\,b'$ to e' and f'; and from these points draw verticals $e'\,c'$ and $f'\,d'$; make $b'\,e'$ equal to $b\,e$, $e'\,c'$ equal to $e\,c$; and similarly for d'. Draw the lower edge parallel to $c'\,d'$ and equal to it in length, and connect with b'.

It will be seen that in isometric drawing parallel lines always appear parallel. It is also true that lines divided proportionally maintain this same relation in isometric drawing.

Fig. 60 shows a block or prism with a semicircular top. Find the isometric of the square circumscribing the circle, then draw the curve by the approximate method. The centers for the back face are found by projecting the front centers back 30° equal to the thickness of the prism, as shown at a and b.

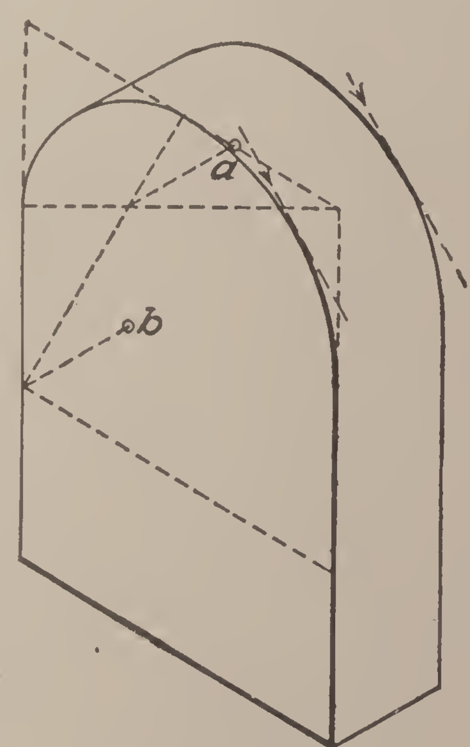


Fig. 60.

The plan and elevation of an oblique pentagonal pyramid are shown in Fig. 61. It is evident that none of the edges of the pyramid can be drawn in isometric as either vertical or 30° lines; hence, a system of co-ordinates must be used as

shown in Fig. 58. This problem illustrates the most general case; and to locate some of the points three co-ordinates must be used, two at 30° and one vertical.

Circumscribe, about the plan of the pyramid, a rectangle which shall have its sides respectively parallel and perpendicular to the ground line. This rectangle is on H, and its vertical projection is in the ground line.

The isometric of this rectangle can be drawn at once with 30° lines, as shown in Fig. 62, *o* being the same point in both figures.

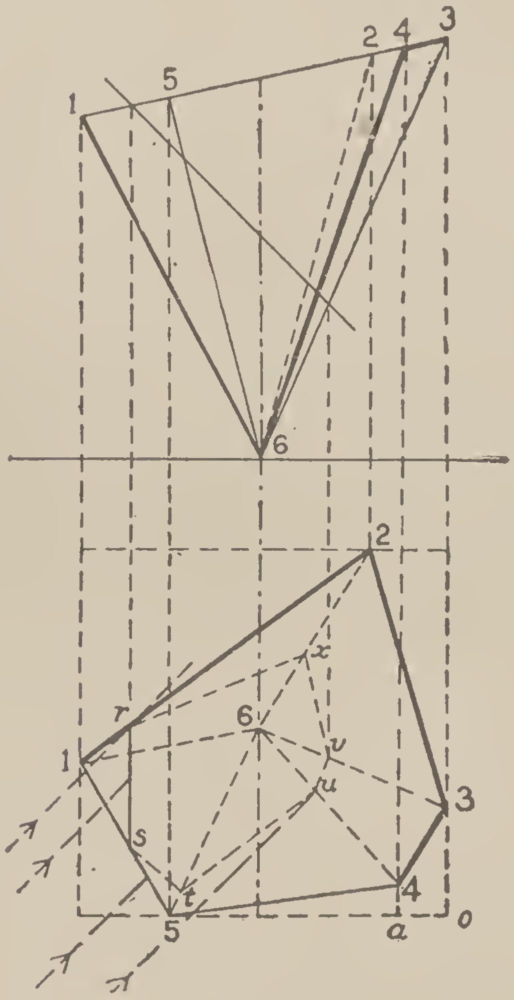


Fig. 61.

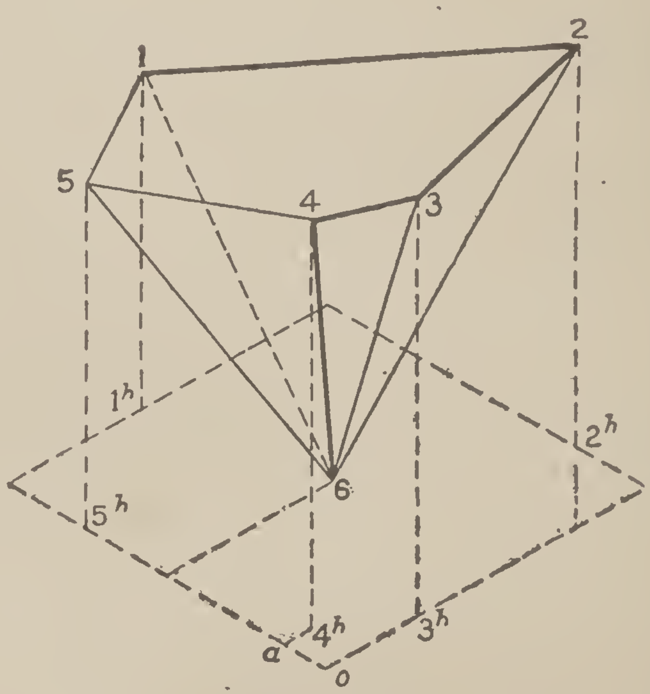


Fig. 62.

The horizontal projection of point 3 is found in isometric at 3^h, at the same distance from *o* as in the plan. That is, *any distance which in plan is parallel to a side of the circumscribing rectangle, is shown in isometric in its true length and parallel to the corresponding side of the isometric rectangle.* If point 3 were on the horizontal plane its isometric would be 3^h, but the point is at the vertical height above H given in the elevation; hence, lay off above 3^h this vertical height, obtaining the actual isometric of the point. To locate 4, draw 4 *a* parallel to the side of the rectangle; then lay

off $o\ a$ and $a\ 4^h$, giving what may be called the isometric plan of 4 Next, the vertical height taken from the elevation locates the isometric of the point in space.

In like manner all the corners of the pyramid, including the apex, are located. The rule is, *locate first in isometric the horizontal projection of a point by one or two 30° co-ordinates; then vertically, above this point, its height as taken from the elevation.* The shade lines cannot be determined here by applying the 30° or 60° triangle, owing to the obliquity of the faces. Since the right front corner of the rectangle in plan was made the point o in isometric, the shade lines must be the same in isometric as in actual projection; so that, if these can be determined in Fig. 61, they may be applied at once to Fig. 62.

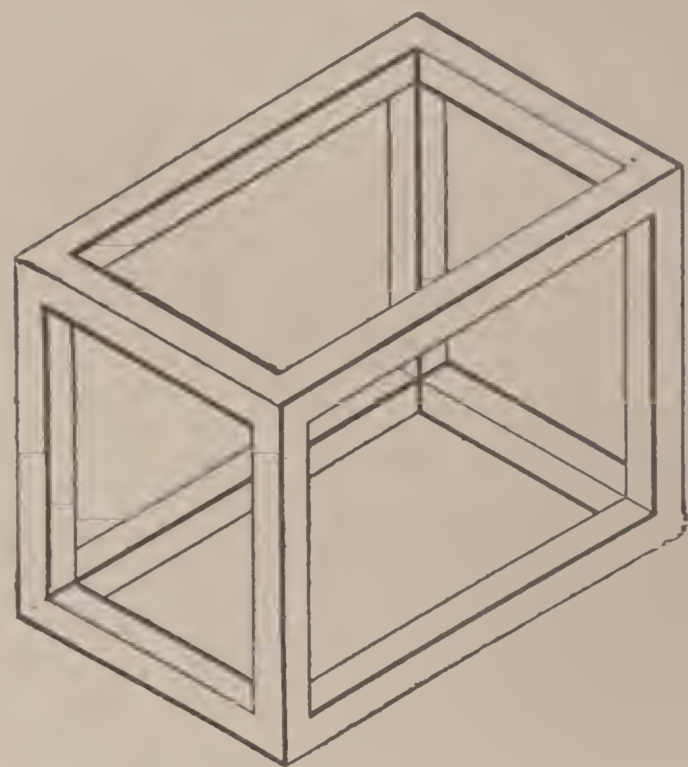


Fig. 63.

The shade lines in Fig. 61 are found by a short method which is convenient to use when the exact shade lines are desired, and when they cannot be determined by applying the 45° triangle. A plane is taken at 45° with the horizontal plane, and parallel to the direction of the ray of light, in such a position as to cut all the surfaces of the pyramid, as shown in

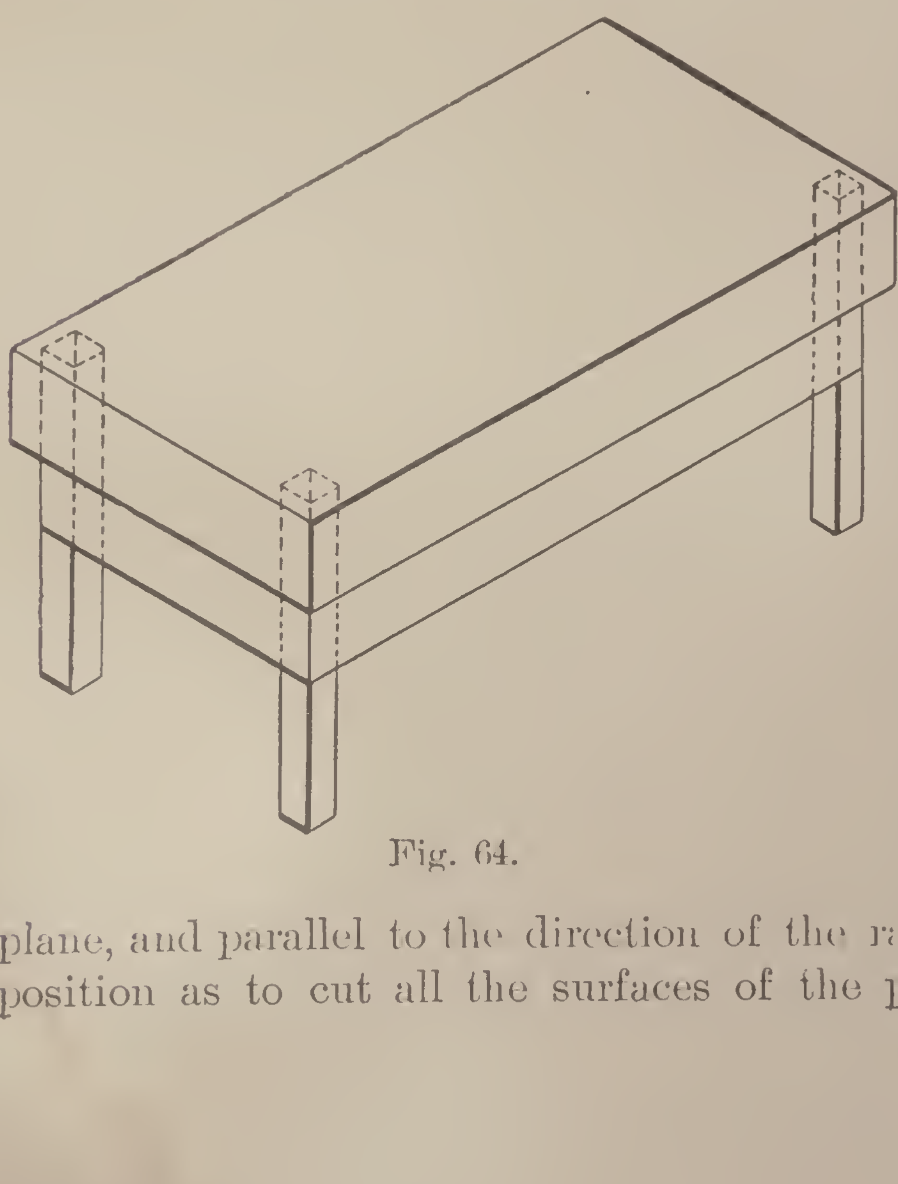


Fig. 64.

elevation. This plane is perpendicular to the vertical plane; hence the section it cuts from the pyramid is readily found in plan by projection. This plane contains some of the rays of light falling upon the pyramid; and we can tell what surfaces these rays strike

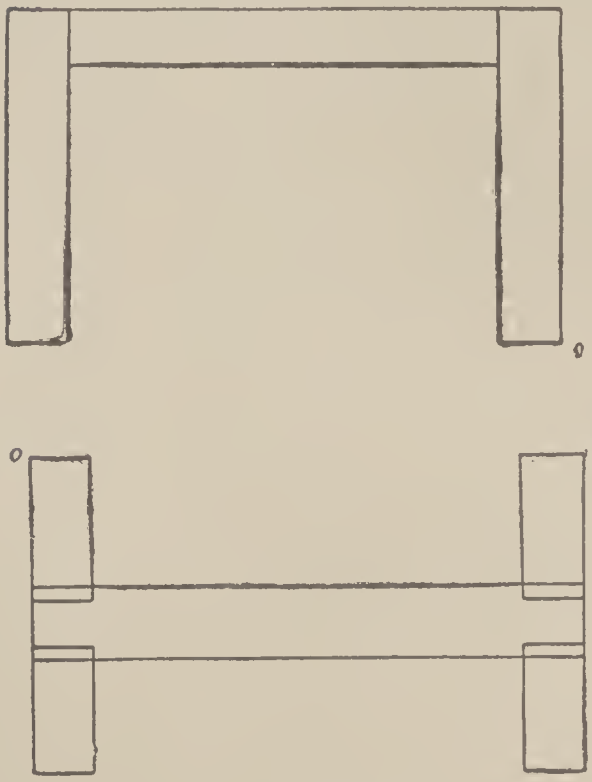


Fig. 65.

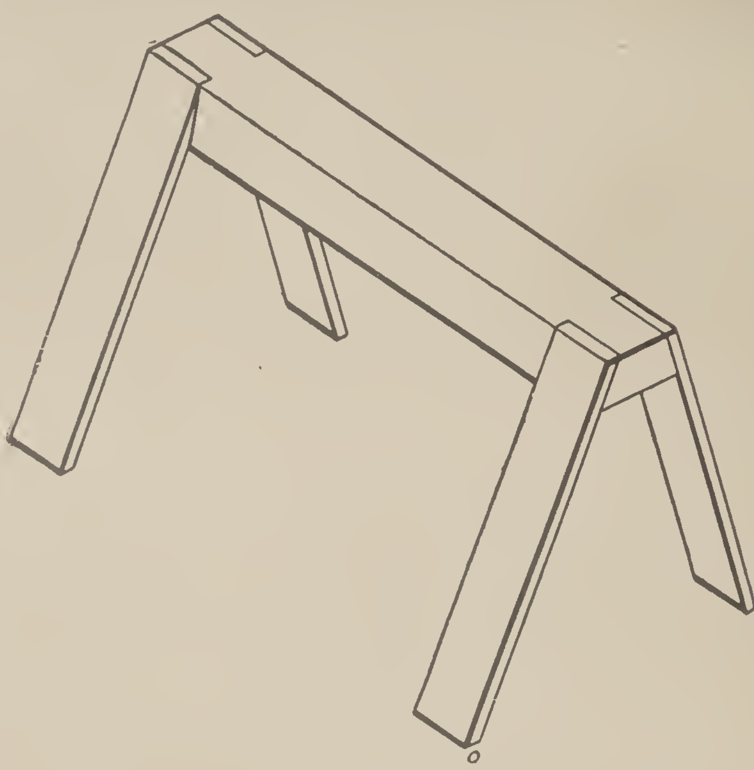


Fig. 66.

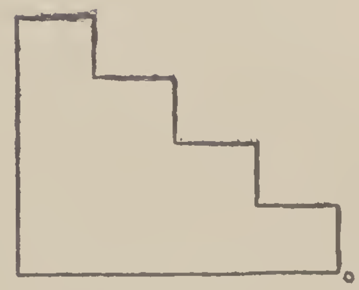


Fig. 67.

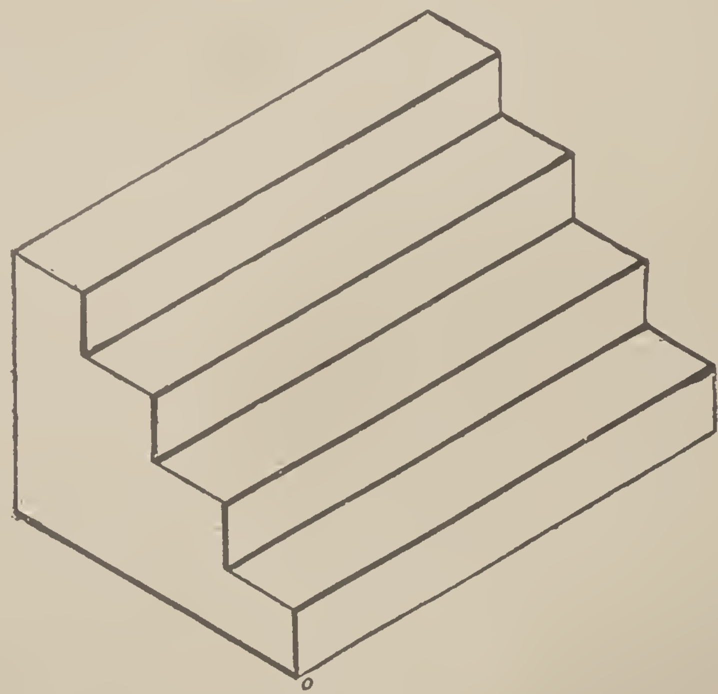


Fig. 68.

and make light, by noticing on the plan what edges of the section are struck by the projections of the rays of light. That is, $r\,s$, $s\,t$, and $t\,u$ receive the rays of light; hence the surfaces on which these lines lie are light. $r\,s$ is on the surface determined by the two lines passing

through r and s, namely, 2 — 1 and 1 — 5; in other words, $r\ s$ is on the base; similarly, $s\ t$ is on the surface 1 — 5 — 6; and $t\ u$ on the surface 4 — 6 — 5. The other surfaces are dark; hence the edges which are between the light and dark faces are the shade lines.

Whenever it is more convenient, a plane parallel to the ray of light and perpendicular to H may be taken, the section found in elevation, and the 45° triangle applied to this section. The same method may be used to determine the exact shade lines of a cone or cylinder in an oblique position.

Figs. 63 to 70 give examples of the isometric of various objects. Fig. 65 is the plan and elevation, and Fig. 66 the

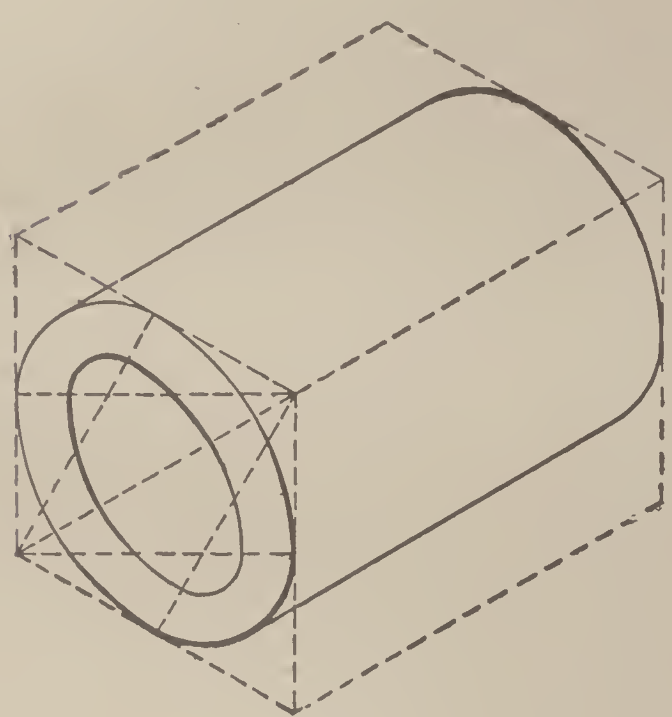


Fig. 69.

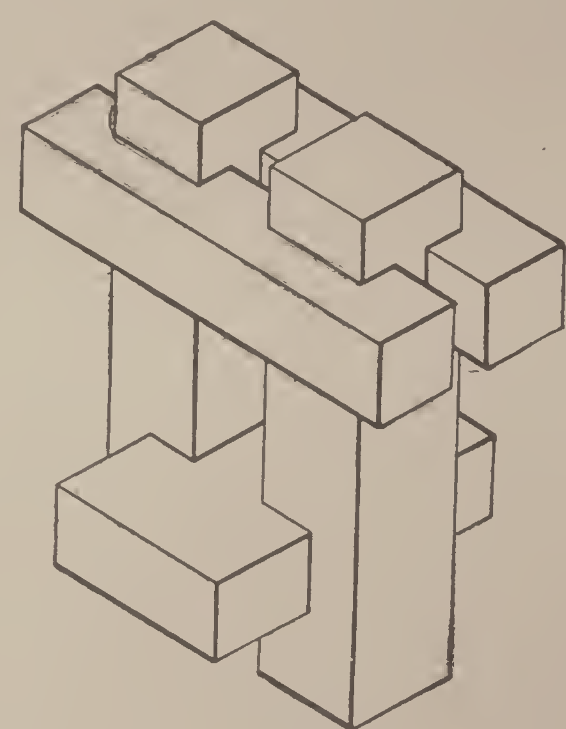


Fig. 70.

isometric, of a carpenter's bench. In Fig. 70, take especial notice of the shade lines. These are put on as if the group were made in one piece; and the shadows cast by the blocks on one another are disregarded. All upper horizontal faces are light, all left-hand (front and back) faces light, and the rest dark.

OBLIQUE PROJECTIONS.

In oblique projection, as in isometric, the end sought for is the same—a more or less complete representation, in one view, of any object. Oblique projection differs from isometric in that one face of the object is represented as if parallel to the vertical plane of projection, the others inclined to it. Another point of

difference is that oblique projection cannot be deduced from orthographic projection, as is isometric.

In oblique projection all lines in the front face are shown in their true lengths and in their true relation to one another, and lines which are perpendicular to this front face are shown in their true lengths at any angle that may be desired for any particular case. Lines not in the plane of the front face nor perpendicular

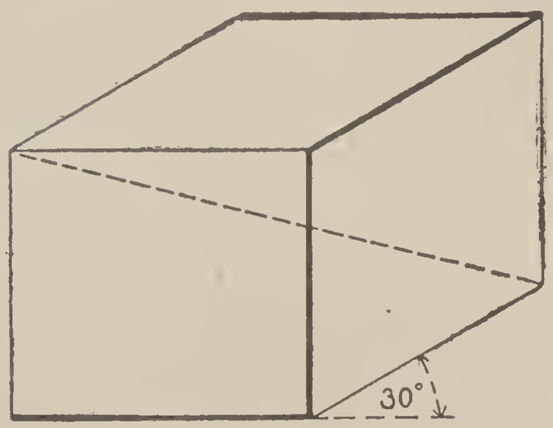


Fig. 71.

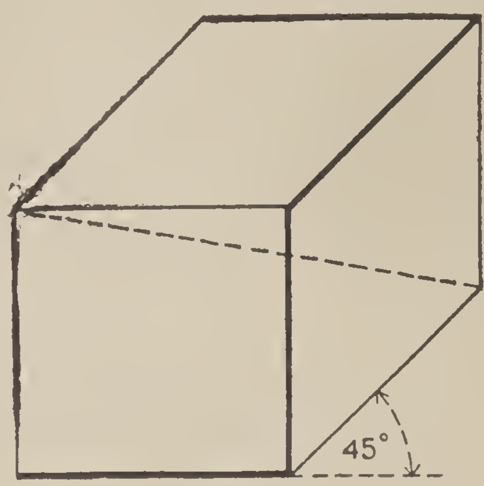


Fig. 72.

to it must be determined by co-ordinates, as in isometric. It will be seen at once that this system possesses some advantages over the isometric, as, for instance, in the representation of circles,

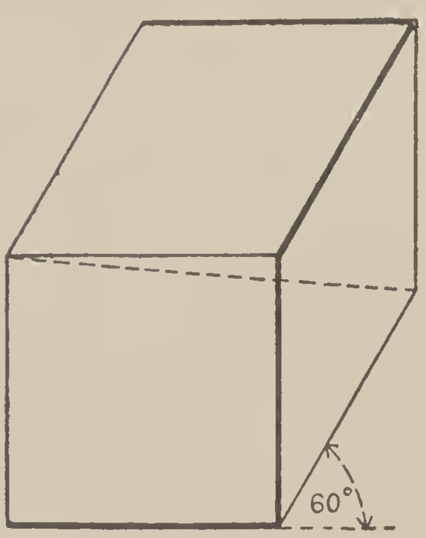


Fig. 73.

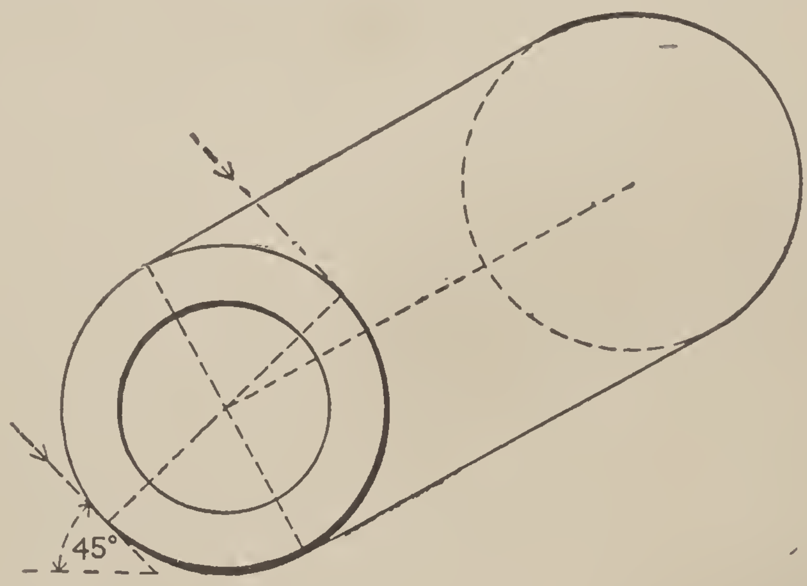


Fig. 74.

as any circle or curve in the front face is actually drawn as such.

The rays of light are still supposed to be parallel to the same diagonal of the cube, that is, sloping downward, toward the plane of projection, and to the right, or downward, backward and to the right. Figs. 71, 72 and 73 show a cube in oblique projection,

with the 30°, 45° and 60° slant respectively. The dotted diagonal represents for each case the direction of the light, and the shade lines follow from this.

The shade lines have the same general position as in isometric

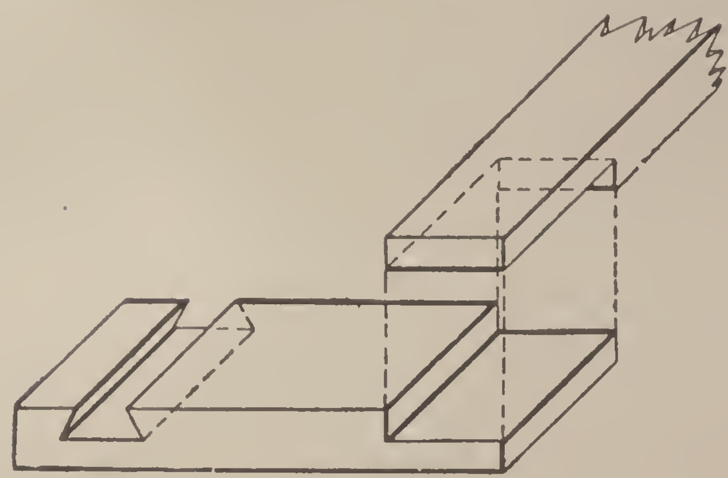


Fig. 75.

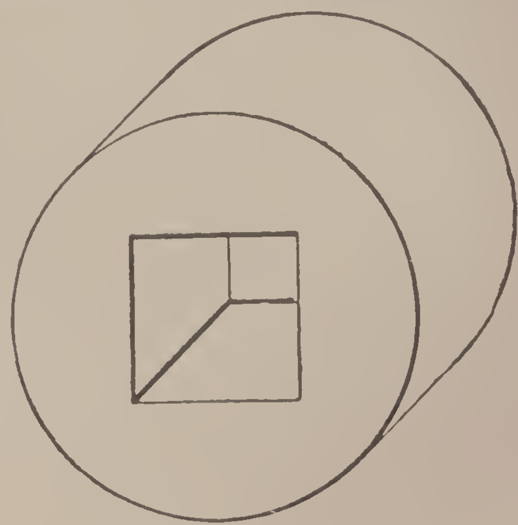


Fig. 76.

drawing, the top, front and left-hand faces being light. No matter what angle may be used for the edges that are perpendicular to the front face, the projection of the diagonal of the cube on this face is always a 45° line; hence, for determining the shade lines on

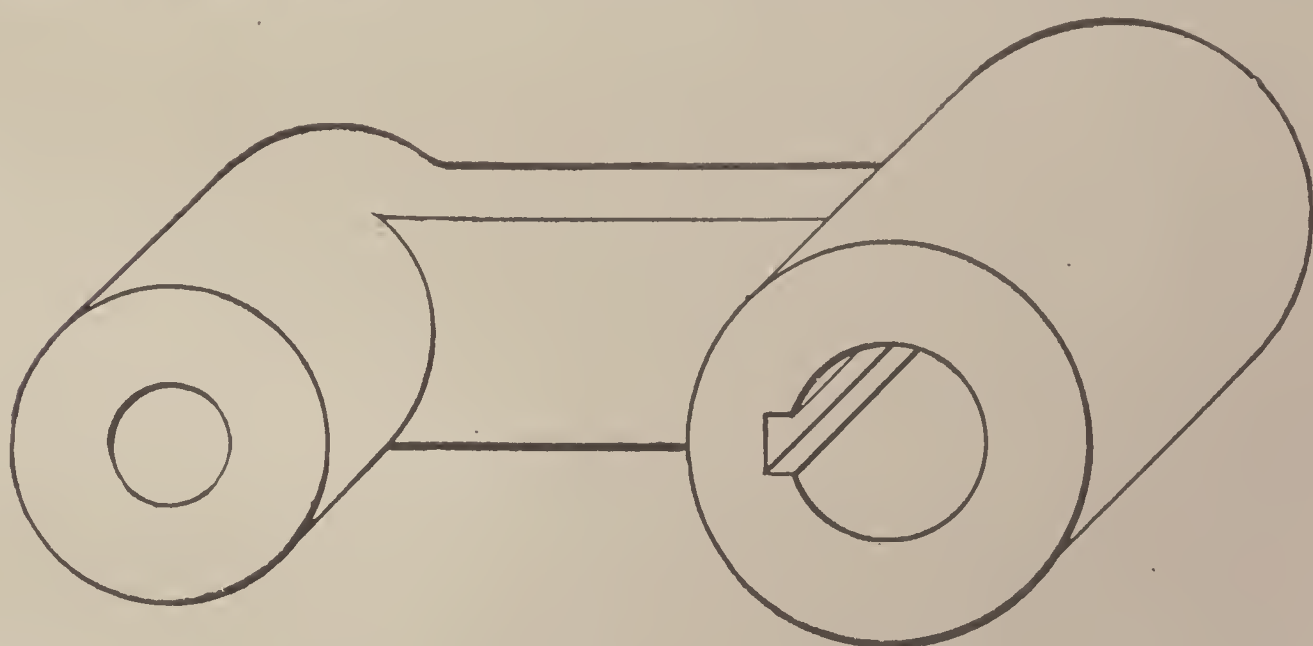


Fig. 77.

any front face, such as the end of the hollow cylinder in Fig. 74, the 45° line is used exactly as in the elevation of ordinary projections.

Figs. 75, 76, 77 and 79 are other examples of oblique projections. Fig. 77 is a crank arm.

The method of using co-ordinates for lines of which the true

lengths are not shown, is illustrated by Figs. 78 and 79. Fig. 79 represents the oblique projection of the two joists shown in plan and elevation in Fig. 78. The dotted lines in the elevation (see Fig. 78) show the heights of the corners above the horizontal stick. The feet of these perpendiculars give the horizontal distances of the top corners from the end of the horizontal piece.

In Fig. 79 lay off from the upper right-hand corner of the front end a distance equal to the distance between the front edge of the inclined piece and the front edge of the bottom piece (see Fig. 78). From this point draw a dotted line parallel to the

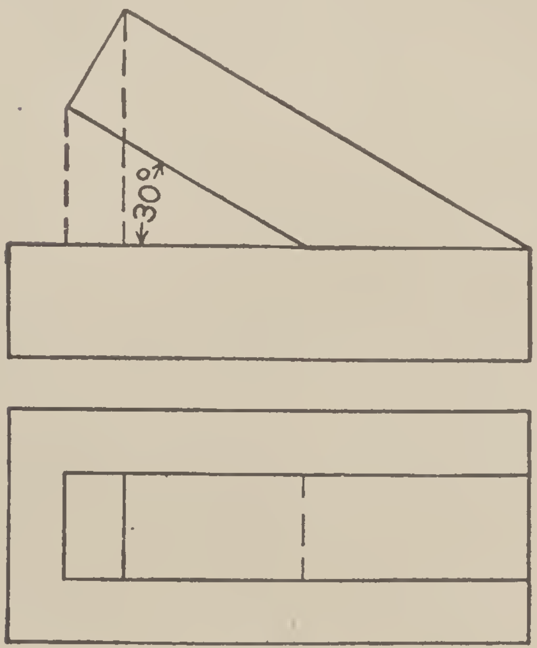


Fig. 78.

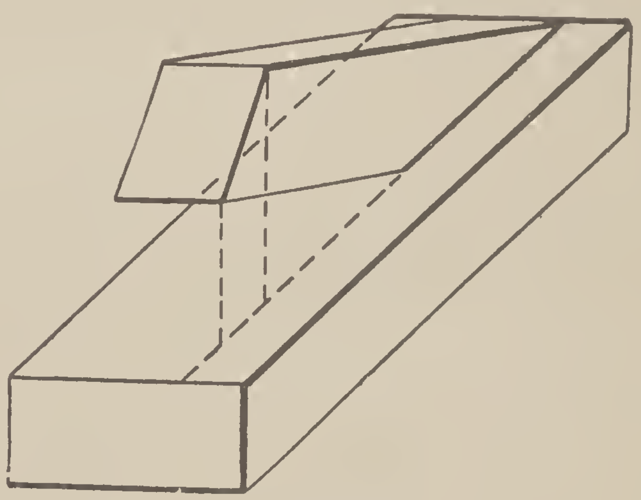


Fig. 79

length. The horizontal distances from the upper left corner to the dotted perpendicular are then marked off on this line. From these points verticals are drawn, and made equal in length to the dotted perpendiculars of Fig. 78, thus locating two corners of the end.

LINE SHADING.

In finely finished drawings it is frequently desirable to make the various parts more readily seen by showing the graduations of light and shade on the curved surfaces. This is especially true of such surfaces as cylinders, cones and spheres. The effect is obtained by drawing a series of parallel or converging lines on the surface at varying distances from one another. Sometimes draftsmen vary the width of the lines themselves. These lines are farther apart on the lighter portion of the surface, and are closer together and heavier on the darker part.

Fig. 80 shows a cylinder with elements drawn on the surface equally spaced, as on the plan. On account of the curvature of the surface the elements are not equally spaced on the elevation, but give the effect of graduation of light. The result is that in elevation the distances between the elements gradually lessen from the center toward each side, thus showing that the cylinder is convex. The effect is intensified, however, if the elements are made heavier, as well as closer together, as shown in Figs. 81 to 87.

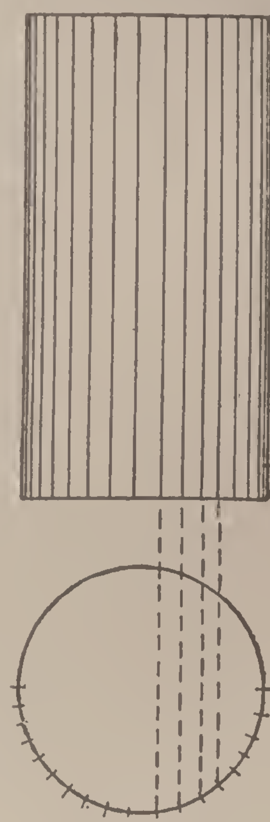


Fig. 80.

Cylinders are often shaded with the light coming in the usual way, the darkest part commencing about where the shade line would actually be on the surface, and the lightest portion a little to the left of the center. Fig. 81 is a cylinder showing the heaviest shade at the right, as this method is often used. Considerable practice is necessary in order to obtain good results; but in this, as in other portions of mechanical drawing, perseverance has its reward. Fig. 82 represents a cylinder in a horizontal position, and Fig. 83 represents a section of a hollow vertical cylinder.

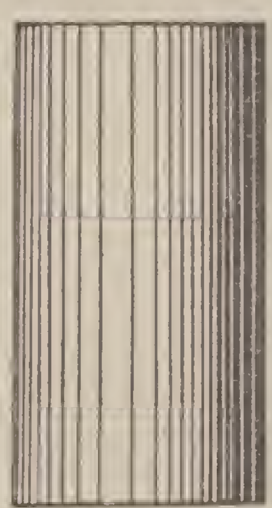


Fig. 81.

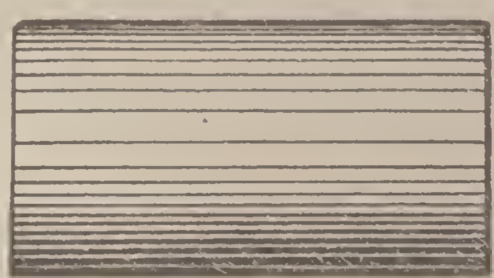


Fig. 82.

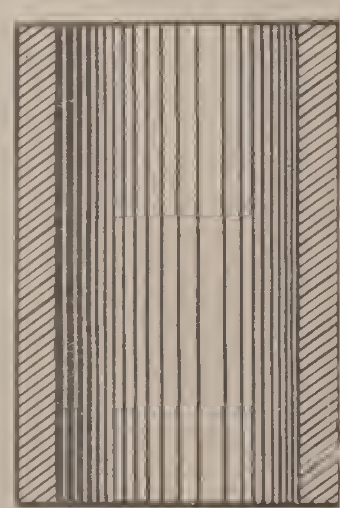


Fig. 83.

Figs. 84 to 87 give other examples of familiar objects.

In the elevation of the cone shown in Fig. 87 the shade lines should diminish in weight as they approach the apex. Unless this is done it will be difficult to avoid the formation of a blot at that point.

LETTERING.

All working drawings require more or less lettering, such as titles, dimensions, explanations, etc. In order that the drawing may appear finished, the lettering must be well done. No style of lettering should ever be used which is not perfectly legible. It is generally best to use plain, easily-made letters which present

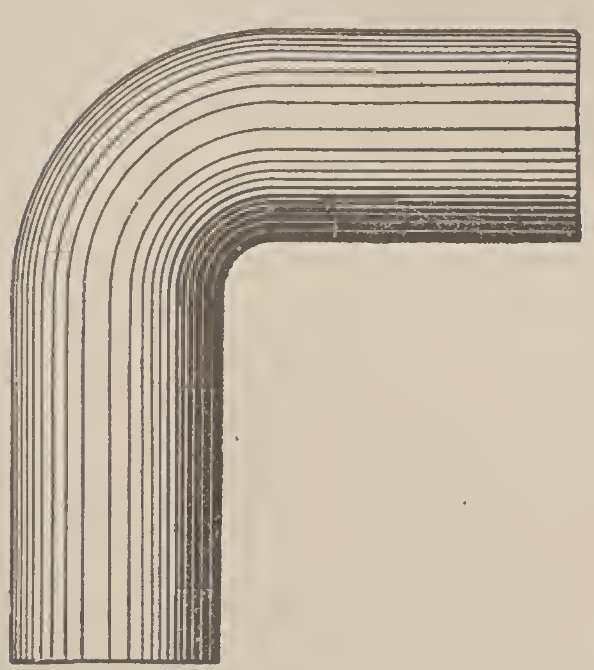


Fig. 84.

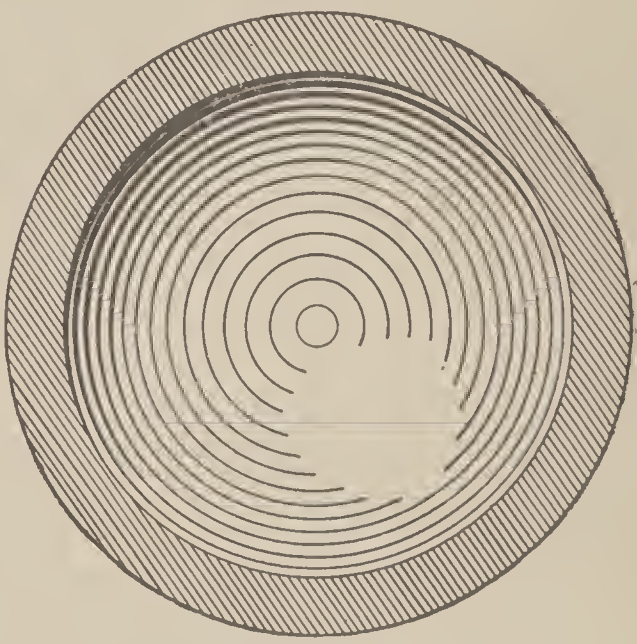


Fig. 85.

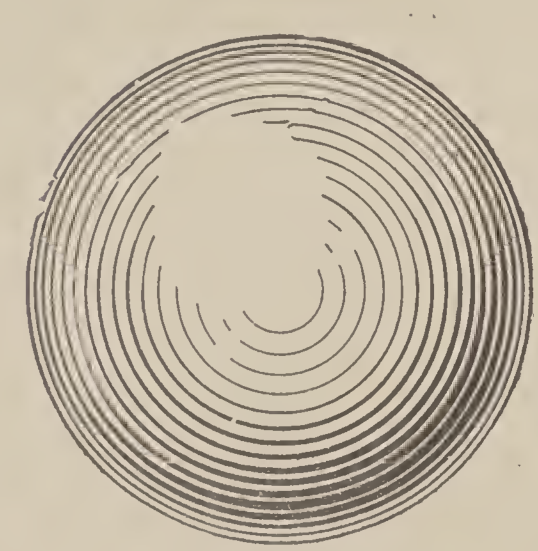


Fig. 86.

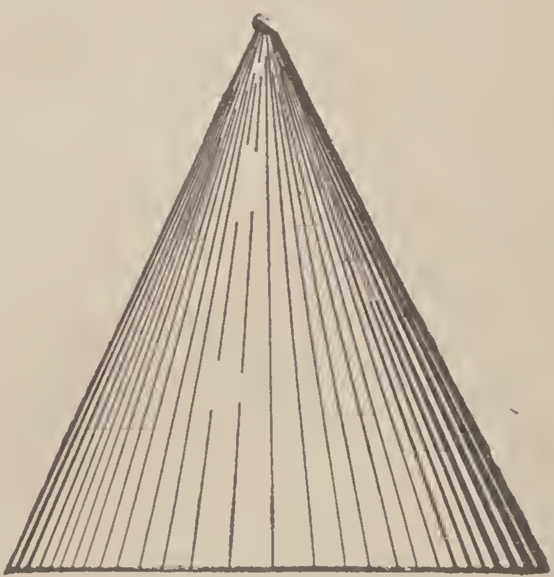


Fig. 87.

a neat appearance. Small letters used on the drawing for notes or directions should be made free-hand with an ordinary writing pen. Two horizontal guide lines should be used to limit the height of the letters; after a time, however, the upper guide line may be omitted.

In the early part of this course the inclined Gothic letter was described, and the alphabet given. The Roman, Gothic and block letters are perhaps the most used for titles. These letters, being of comparatively large size, are generally made mechanically; that is, drawing instruments are used in their construction. In order that the letters may appear of the same height, some of them, owing to their shape, must be made a little higher than the others. This is the case with the letters curved at the top and bottom, such as C, O, S, etc., as shown somewhat exaggerated in Fig. 88. Also, the letter A should extend a little above, and V a little below, the guide lines, because if made of the same height as the others they will appear shorter. This is true of all capitals, whether of Roman, Gothic, or other alphabets. In the block letter however, they are frequently all of the same size.

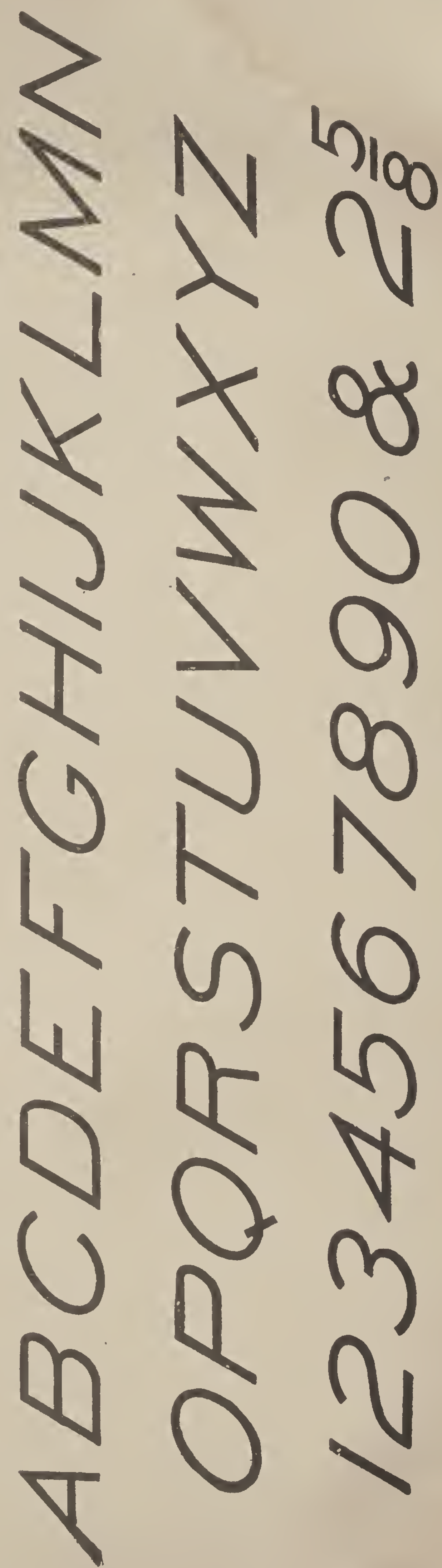
There is no absolute size or proportion of letters, as the dimensions are regulated by the amount of space in which the letters are to be placed, the size of the drawing, the effect desired, etc. In some cases letters are made so that the height is greater than the width, and sometimes the reverse; sometimes the height and width are the same. This last proportion is the most common. Certain relations of width, however, should be observed. Thus, in whatever style of alphabet used, the W should be the widest letter; J the narrowest, M and T next widest to W, then A and B. The other letters are of about the same width.

In the vertical Gothic alphabet, the average height is that of B, D, E, F, etc., and the additional height of the curved letters and of the A and V is very slight. The horizontal cross lines of such letters as E, F, H, etc., are slightly above the center; those of A, G and P slightly below.

For the inclined letters, 60° is a convenient angle, although they may be at any other angle suited to the convenience or fancy of the draftsman. Many draftsmen use an angle of about 70°.

The letters of the Roman alphabet, whether vertical or inclined, are quite ornamental in effect if well made, the inclined Roman being a particularly attractive letter, although rather difficult to make. The block letter is made on the same general plan as the Gothic, but much heavier. Small squares are taken as

Fig. 88. Vertical Gothic Capitals.



Inclined Gothic Capitals.

the unit of measurement, as shown. The use of this letter is not advocated for general work, although if made merely in outline the effect is pleasing. The styles of numbers corresponding with the alphabets of capitals given here, are also inserted. When a fraction, such as $2\frac{5}{8}$ is to be made, the proportion should be about as shown. For small letters, usually called lower-case letters,

abcdefghijklmn
opqrstuvwxyz

Fig. 89.

abcdefghijklmn
opqrstuvwxyz

Fig. 90.

abcdefghijklmn
opqrstuvwxyz

Fig. 91.

the height may be made about two-thirds that of the capitals. This proportion, however, varies in special cases.

The principal lower-case letters in general use among draftsmen are shown in Figs. 89, 90, 91 and 92. The Gothic letters shown in Figs. 89 and 90 are much easier to make than the Roman letters in Figs. 91 and 92. These letters, however, do not

ABCDEFGHIJKLMN

OPQRSTUVWXYZ

1234567890 & $2\frac{5}{8}$

Vertical Roman Capitals.

ABCDEFGHIJKLMN

OPQRSTUVWXYZ

1234567890 & $2\frac{5}{8}$

Inclined Roman Capitals.

give as finished an appearance as the Roman. As has already been stated in Mechanical Drawing, Part I, the inclined letter is easier to make because slight errors are not so apparent.

One of the most important points to be remembered in lettering is the spacing. If the letters are finely executed but poorly spaced, the effect is not good. To space letters correctly and rapidly, requires considerable experience; and rules are of little value on account of the many combinations in which letters are

abcdefghijklmn

opqrstuvwxyz

Fig. 92.

found. A few directions, however, may be found helpful. For instance, take the word TECHNICALITY, Fig. 93. If all the spaces were made equal, the space between the L and the I would appear to be too great, and the same would apply to the space between the I and the T. The space between the H and the N and that between the N and the I would be insufficient. In general, when the vertical side of one letter is followed by the vertical side of another, as in H E, H B, I R, etc., the maximum space

TECHNICALITY

Fig. 93.

should be allowed. Where T and A come together the least space is given, for in this case the top of the T frequently extends over the bottom of the A. In general, the spacing should be such that a uniform appearance is obtained. For the distances between words in a sentence, a space of about $1\frac{1}{2}$ the width of the average letter may be used. The space, however, depends largely upon the desired effect

For large titles, such as those placed on charts, maps, and some large working drawings, the letters should be penciled before inking. If the height is made equal to the width considerable time and labor will be saved in laying out the work. This is especially true with such Gothic letters as O, Q, C, etc., as these letters may then be made with compasses. If the letters are of sufficient size, the outlines may be drawn with the ruling pen or compasses, and the spaces between filled in with a fine brush.

The titles for working drawings are generally placed in the lower right-hand corner. Usual a draftsman has his choice of

Block Letters.

letters, mainly because after he has become used to making one style he can do it rapidly and accurately. However, in some drafting rooms the head draftsman decides what lettering shall be used. In making these titles, the different alphabets are selected to give the best results without spending too much time. In most work the letters are made in straight lines, although we frequently find a portion of the title lettered on an arc of a circle.

In Fig. 94 is shown a title having the words CONNECTING ROD lettered on an arc of a circle. To do this work requires considerable patience and practice. First draw the vertical center

line as shown at C in Fig. 94. Then draw horizontal lines for the horizontal letters. The radii of the arcs depend upon the general arrangement of the entire title, and this is a matter of taste. The difference between the arcs should equal the height of the letters. After the arc is drawn, the letters should be sketched in pencil to find their approximate positions. After this is done, draw radial lines from the center of the letters to the center of the arcs.

Fig. 94.

These lines will be the centers of the letters, as shown at A, B, D and E. The vertical lines of the letters should not radiate from the center of the arc, but should be parallel to the center lines already drawn; otherwise the letters will appear distorted. Thus, in the letter N the two verticals are parallel to the line A. The same applies to the other letters in the alphabet.

Tracing. Having finished the pencil drawing, the next step is the inking. In some offices the pencil drawing is made on a thin, tough paper, called board paper, and the inking is done over the pencil drawing, in the manner with which the student is already familiar. It is more common to do the inking on thin, transparent cloth, called tracing cloth, which is prepared for the purpose. This tracing cloth is made of various kinds, the kind in ordinary use being what is known as "dull back," that is, one side is finished and the other side is left dull. Either side may be used to draw upon, but most draftsmen prefer the dull side. If a drawing is to be traced it is a good plan to use a 3H or 4H pencil, so that the lines may be easily seen through the cloth.

The tracing cloth is stretched smoothly over the pencil drawing and a little powdered chalk rubbed over it with a dry cloth, to remove the slight amount of grease or oil from the surface and make it take the ink better. The dust must be carefully brushed or wiped off with a soft cloth, after the rubbing, or it will interfere with the inking.

The drawing is then made in ink on the tracing cloth, after the same general rules as for inking the paper, but care must be taken to draw the ink lines exactly over the pencil lines which are on the paper underneath, and which should be just heavy enough to be easily seen through the tracing cloth. The ink lines should be firm and fully as heavy as for ordinary work. In tracing, it is better to complete one view at a time, because if parts of several views are traced and the drawing left for a day or two, the cloth is liable to stretch and warp so that it will be difficult to complete the views and make the new lines fit those already drawn and at the same time conform to the pencil lines underneath. For this reason it is well, when possible, to complete a view before leaving the drawing for any length of time, although of course on views in which there is a good deal of work this cannot always be done. In this case the draftsman must manipulate his tracing cloth and instruments to make the lines fit as best he can. A skillful draftsman will have no trouble from this source, but the beginner may at first find difficulty.

Inking on tracing cloth will be found by the beginner to be quite different from inking on the paper to which he has been accustomed, and he will doubtless make many blots and think at

first that it is hard to make a tracing. After a little practice, however, he will find that the tracing cloth is very satisfactory and that a good drawing can be made on it quite as easily as on paper.

The necessity for making erasures should be avoided, as far as possible, but when an erasure must be made a good ink rubber or typewriter eraser may be used. If the erased line is to have ink placed on it, such as a line crossing, it is better to use a soft rubber eraser. All moisture should be kept from the cloth.

Blue Printing. The tracing, of course, cannot be sent into the shop for the workmen to use, as it would soon become soiled and in time destroyed, so that it is necessary to have some cheap and rapid means of making copies from it. These copies are made by the process of blue printing in which the tracing is used in a manner similar to the use made of a negative in photography.

Almost all drafting rooms have a frame for the purpose of making blue prints. These frames are made in many styles, some simple, some elaborate. A simple and efficient form is a flat surface usually of wood, covered with padding of soft material, such as felting. To this is hinged the cover, which consists of a frame similar to a picture frame, in which is set a piece of clear glass. The whole is either mounted on a track or on some sort of a swinging arm, so that it may readily be run in and out of a window.

The print is made on paper prepared for the purpose by having one of its surfaces coated with chemicals which are sensitive to sunlight. This coated paper, or blue-print paper, as it is called, is laid on the padded surface of the frame with its coated side uppermost; the tracing laid over it right side up, and the glass pressed down firmly and fastened in place. Springs are frequently used to keep the paper, tracing, etc., against the glass. With some frames it is more convenient to turn them over and remove the backs. In such cases the tracing is laid against the glass, face down; the coated paper is then placed on it with the coated side against the tracing cloth.

The sun is allowed to shine upon the drawing for a few minutes, then the blue-print paper is taken out and thoroughly washed in clean water for several minutes and hung up to dry.

If the paper has been recently prepared and the exposure properly timed, the coated surface of the paper will now be of a clear, deep blue color, except where it was covered by the ink lines, where it will be perfectly white.

The action has been this: Before the paper was exposed to the light the coating was of a pale yellow color, and if it had then been put in water the coating would have all washed off, leaving the paper white. In other words, before being exposed to the sunlight the coating was soluble. The light penetrated the transparent tracing cloth and acted upon the chemicals of the coating, changing their nature so that they became insoluble; that is, when put in water, the coating, instead of being washed off, merely turned blue. The light could not penetrate the ink with which the lines, figures, etc., were drawn, consequently the coating under these was not acted upon and it washed off when put in water, leaving a white copy of the ink drawing on a blue background. If running water cannot be used, the paper must be washed in a sufficient number of changes until the water is clear. It is a good plan to arrange a tank having an overflow, so that the water may remain at a depth of about 6 or 8 inches.

The length of time to which a print should be exposed to the light depends upon the quality and freshness of the paper, the chemicals used and the brightness of the light. Some paper is prepared so that an exposure of one minute, or even less, in bright sunlight, will give a good print and the time ranges from this to twenty minutes or more, according to the proportions of the various chemicals in the coating. If the full strength of the sunlight does not strike the paper, as, for instance, if clouds partly cover the sun, the time of exposure must be lengthened.

Assembly Drawing. We have followed through the process of making a detail drawing from the sketches to the blue print ready for the workmen. Such a detail drawing or set of drawings shows the form and size of each piece, but does not show how the pieces go together and gives no idea of the machine as a whole. Consequently, a general drawing or assembly drawing must be made, which will show these things. Usually two or more views are necessary, the number depending upon the complexity of the machine. Very often a cross-section through some part of the

machine, chosen so as to give the best general idea with the least amount of work, will make the drawing clearer.

The number of dimensions required on an assembly drawing depends largely upon the kind of machine. It is usually best to give the important over-all dimensions and the distance between the principal center lines. Care must be taken that the over-all dimensions agree with the sum of the dimensions of the various details. For example, suppose three pieces are bolted together, the thickness of the pieces according to the detail drawing, being one inch, two inches, and five and one-half inches respectively; the sum of these three dimensions is eight and one-half inches and the dimensions from outside on the assembly drawing, if given at all, must agree with this. It is a good plan to add these over-all dimensions, as it serves as a check and relieves the mechanic of the necessity of adding fractions.

FORMULA FOR BLUE-PRINT SOLUTION.

Dissolve thoroughly and filter.

A.	Red Prussiate of potash	2½ ounces,
	Water	1 pint.
B.	Ammonio-Citrate of iron	4 ounces,
	Water	1 pint.

Use equal parts of A and B.

FORMULA FOR BLACK PRINTS

Negatives. White lines on blue ground; prepare the paper with

Ammonio-Citrate of iron	40 grains,
Water	1 ounce.

After printing wash in water.

Positives. Black lines on white ground; prepare the paper with:

Iron perchloride	616 grains,
Oxalic Acid	308 grains,
Water	14 ounces.

Develop in	Gallic Acid	1 ounce,
	Citric Acid	1 ounce,
	Alum	8 ounces.

Use $1\frac{1}{4}$ ounces of developer to one gallon of water. Paper is fully exposed when it has changed from yellow to white.

PLATES.

PLATE IX.

The plates of this Instruction Paper should be laid out at the same size as the plates in Parts I and II. The center lines and border lines should also be drawn as described.

First draw two ground lines across the sheet, 3 inches below the upper border line and 3 inches above the lower border line. The first problem on each ground line is to be placed 1 inch from the left border line; and spaces of about 1 inch should be left between the figures.

Isolated points are indicated by a small cross X, and projections of lines are to be drawn full unless invisible. All construction lines should be fine dotted lines. Given and required lines should be drawn full.

Problems on Upper Ground Line:

1. Locate both projections of a point on the horizontal plane 1 inch from the vertical plane.

2. Draw the projections of a line 2 inches long which is parallel to the vertical plane and which makes an angle of 45 degrees with the horizontal plane and slants upward to the right. The line should be 1 inch from the vertical plane and the lower end ½ inch above the horizontal.

3 Draw the projections of a line 1½ inches long which is parallel to both planes, 1 inch above the horizontal, and ¾ inch from the vertical.

4. Draw the plan and elevation of a line 2 incnes long which is parallel to H and makes an angle of 30 degrees with V. Let the right-hand end of the line be the end nearer V, ½ inch from V. The line to be 1 inch above H.

5. Draw the plan and elevation of a line 1½ inches long which is perpendicular to the horizontal plane and 1 inch from the vertical. Lower end of line is ½ inch above H.

6. Draw the projections of a line 1 inch long which is perpendicular to the vertical plane and 1½ inches above the horizontal. The end of the line nearer V, or the back end, is ½ inch from V.

PLATE IX

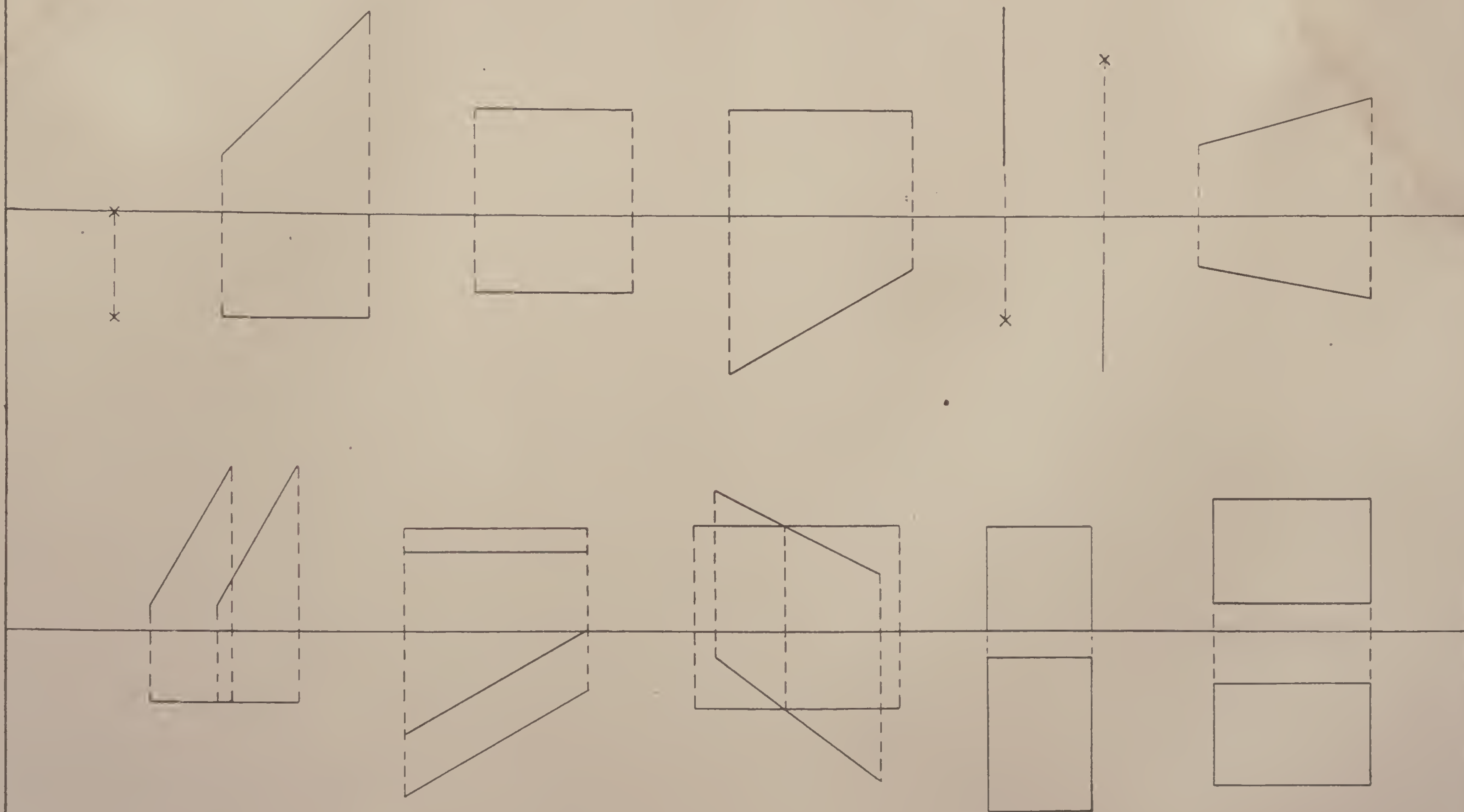


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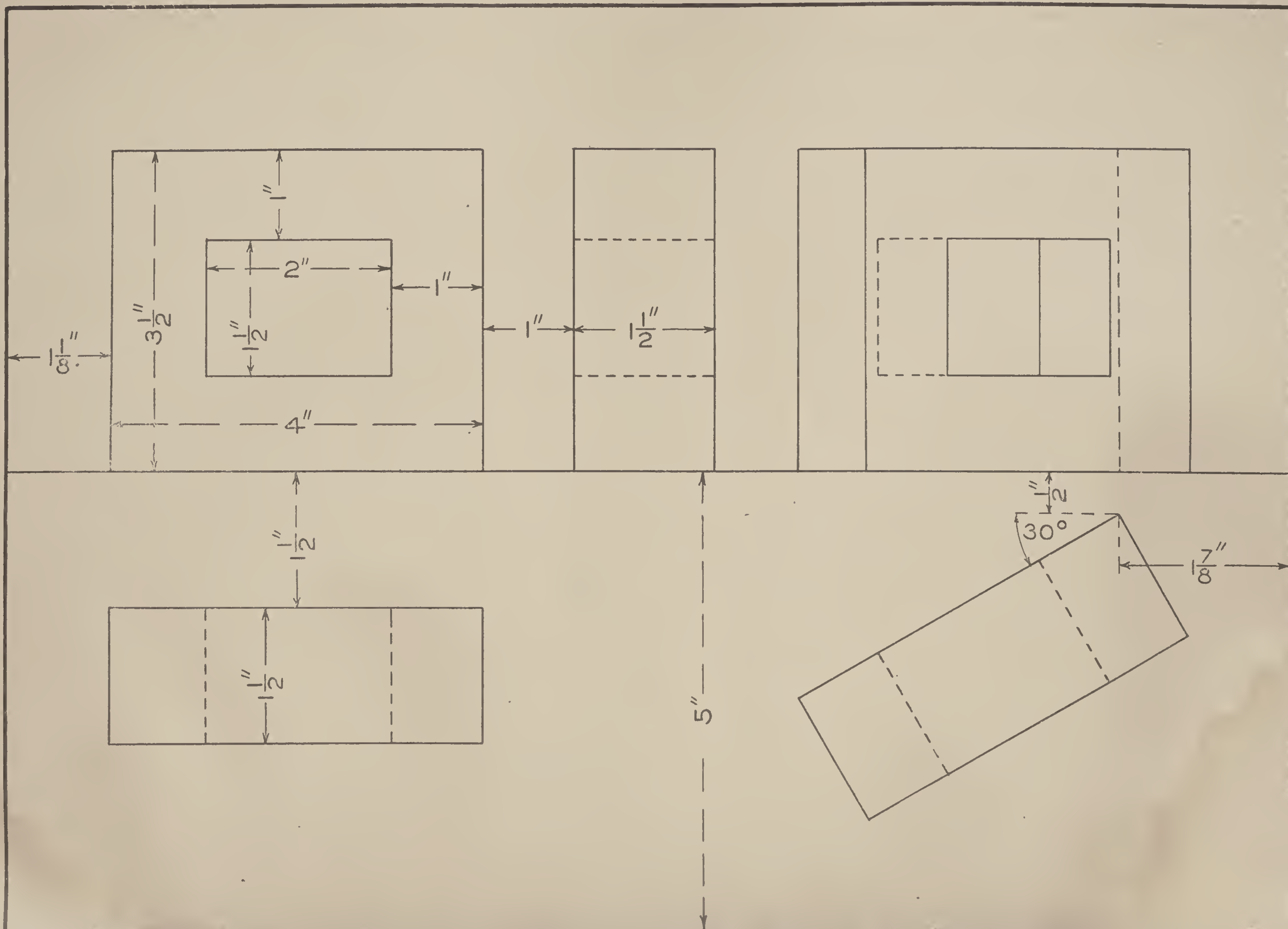
PLATE X



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7. Draw two projections which shall represent a line oblique to both planes.

Note. Leave 1 inch between this figure and the right-hand border line.

Problems on Lower Ground Line:

8. Draw the projections of two parallel lines each $1\frac{1}{2}$ inches long. The lines are to be parallel to the vertical plane and to make angles of 60 degrees with the horizontal. The lower end of each line is $\frac{1}{4}$ inch above H. The right-hand end of the right-hand line is to be $2\frac{3}{4}$ inches from the left-hand margin.

9. Draw the projections of two parallel lines each 2 inches long. Both lines to be parallel to the horizontal and to make an angle of 30 degrees with the vertical. The lower line to be $\frac{3}{4}$ inch above H, and one end of one line to be against V.

10. Draw the projections of two intersecting lines. One 2 inches long to be parallel to both planes, 1 inch above H, and $\frac{3}{4}$ inch from the vertical; and the other to be oblique to both planes and of any desired length.

11. Draw plan and elevation of a prism 1 inch square and $1\frac{1}{2}$ inches long. The prism to have one side on the horizontal plane, and its long edges to be perpendicular to V. The back end of the prism is $\frac{1}{4}$ inch from the vertical plane.

12. Draw plan and elevation of a prism the same size as given above, but with the long edges parallel to both planes, the lower face of the prism to be parallel to H and $\frac{1}{4}$ inch above it. The back face to be $\frac{1}{2}$ inch from V.

PLATE X.

The ground line is to be in the middle of the sheet, and the location and dimensions of the figures are to be as given. The first figure shows a rectangular block with a rectangular hole cut through from front to back. The other two figures represent the same block in different positions. The second figure is the end or profile projection of the block. The same face is on H in all three positions. Be careful not to omit the shade lines. The figures given on the plate for dimensions, etc., are to be used but not repeated on the plate by the student.

PLATE XI.

Three ground lines are to be used on this plate, two at the left $4\frac{1}{2}$ inches long and 3 inches from top and bottom margin lines; and one at the right, half way between the top and bottom margins, $9\frac{1}{2}$ inches long.

The figures 1, 2, 3 and 4 are examples for finding the true lengths of the lines. Begin No. 1 $\frac{3}{4}$ inch from the border, the vertical projection $1\frac{3}{4}$ inches long, one end on the ground line and inclined at 30°. The horizontal projection has one end $\frac{1}{2}$ inch from V, and the other $1\frac{1}{2}$ inches from V. Find the true length of the line by completing the construction commenced by swinging the arc, as shown in the figure.

Locate the left-hand end of No. 2 3 inches from the border, 1 inch above H, and $\frac{5}{8}$ inch from V. Extend the vertical projection to the ground line at an angle of 45°, and make the horizontal projection at 30°. Complete the construction for true length as commenced in the figure.

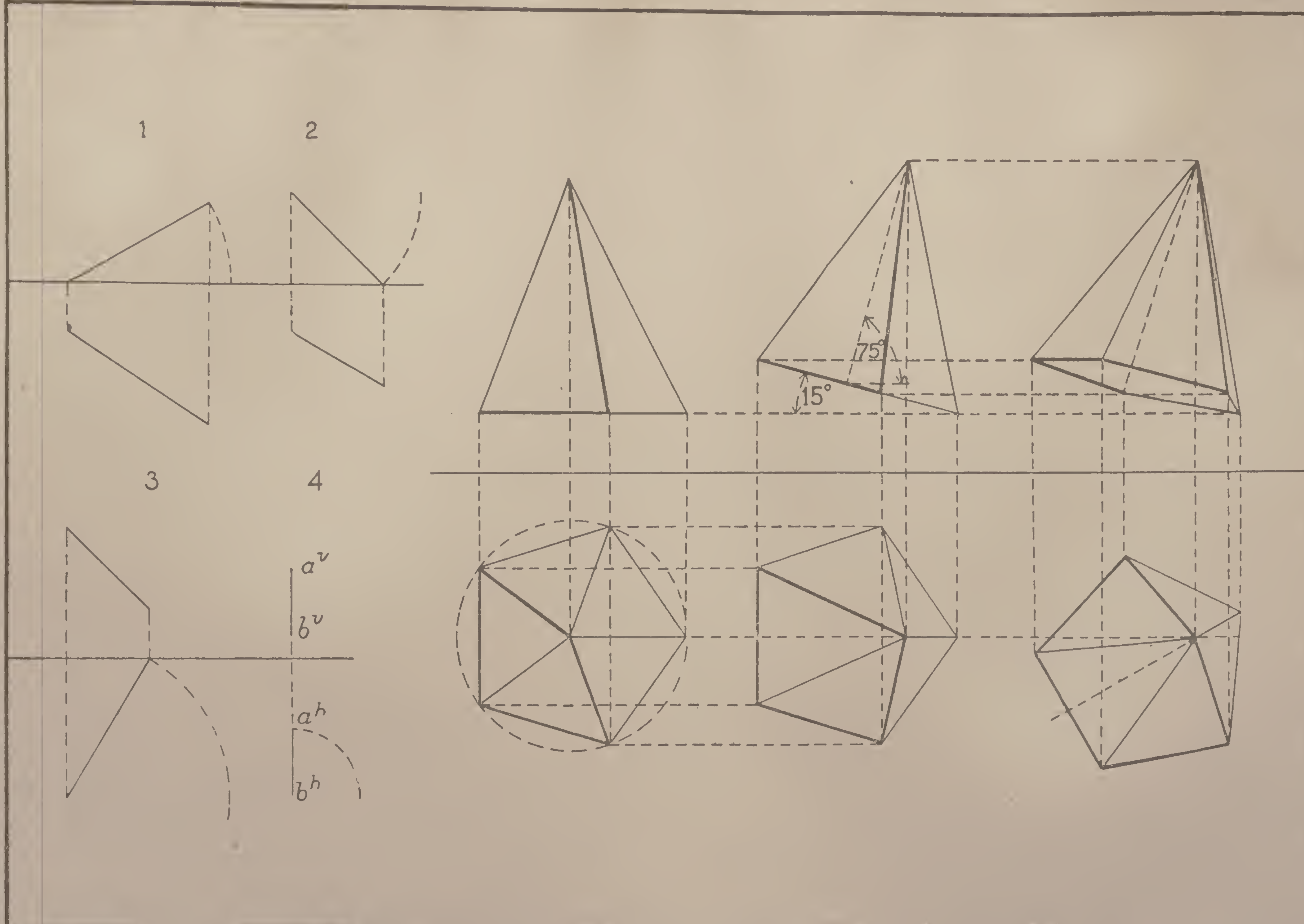
In Figs. 3 and 4, the true lengths are to be found by completing the revolutions indicated. The left-hand end of Fig. 3 is $\frac{3}{4}$ inch from the margin, $1\frac{1}{2}$ inches from V, and $1\frac{3}{8}$ inches above H. The horizontal projection makes an angle of 60° and extends to the ground line, and the vertical projection is inclined at 45°.

The fourth figure is 3 inches from the border, and represents a line in a profile plane connecting points a and b. a is $1\frac{1}{4}$ inches above H and $\frac{3}{4}$ inch from V; and b is $\frac{1}{4}$ inch above H and $1\frac{1}{2}$ inches from V.

The figures for the middle ground line represent a pentagonal pyramid in three positions. The first position is the pyramid with the axis vertical, and the base $\frac{5}{8}$ inch above the horizontal. The height of the pyramid is $2\frac{1}{2}$ inches, and the diameter of the circle circumscribed about the base is $2\frac{1}{2}$ inches. The center of the circle is 6 inches from the left margin and $1\frac{3}{4}$ inches from V. Spaces between figures to be $\frac{3}{4}$ inch.

In the second figure the pyramid has been revolved about the right-hand corner of the base as an axis, through an angle of 15°. The axis of the pyramid, shown dotted, is therefore at 75°. The method of obtaining 75° and 15° with the triangles was shown in

PLATE XI



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Part I. From the way in which the pyramid has been revolved, all angles with V must remain the same as in the first position, hence the vertical projection will be the same shape and size as before. All points of the pyramid remain the same distance from V. The points on the plan are found on T-square lines through the corners of the first plan and directly beneath the points in elevation. In the third position the pyramid has been swung around, about a vertical line through the apex as axis, through 30°. The angle with the horizontal plane remains the same; consequently the plan is the same size and shape as in the

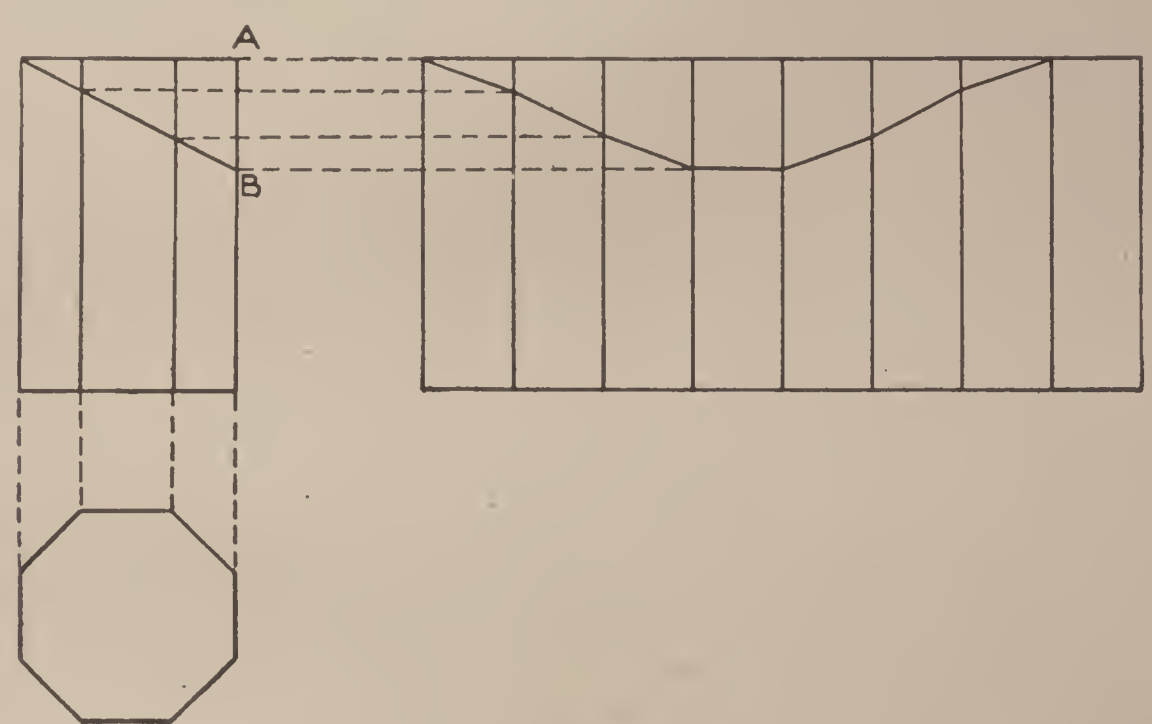


Fig. 96.

second position, but at a different angle with the ground line. Heights of all points of the pyramid have not changed this time, and hence are projected across from the second elevation. Shade lines are to be put on between the light and dark surfaces as determined by the 45° triangle.

PLATE XII.

Developments.

On this plate draw the developments of a truncated octagonal prism, and of a truncated pyramid having a square base. The arrangement on the plate is left to the student; but we should suggest that the truncated prism and its development be placed at

the left, and that the development of the truncated pyramid be placed under the development of the prism; the truncated pyramid may be placed at the right.

The prism and its development are shown in Fig. 96. The prism is 3 inches high, and the base is inscribed in a circle $2\frac{1}{8}$ inches in diameter. The plane forming the truncated prism is passed as indicated, the distance A B being 1 inch. Ink a sufficient number of construction lines to show clearly the method of finding the development.

The pyramid and its development are shown in Fig. 97. Each side of the square base is 2 inches, and the altitude is $3\frac{1}{2}$ inches.

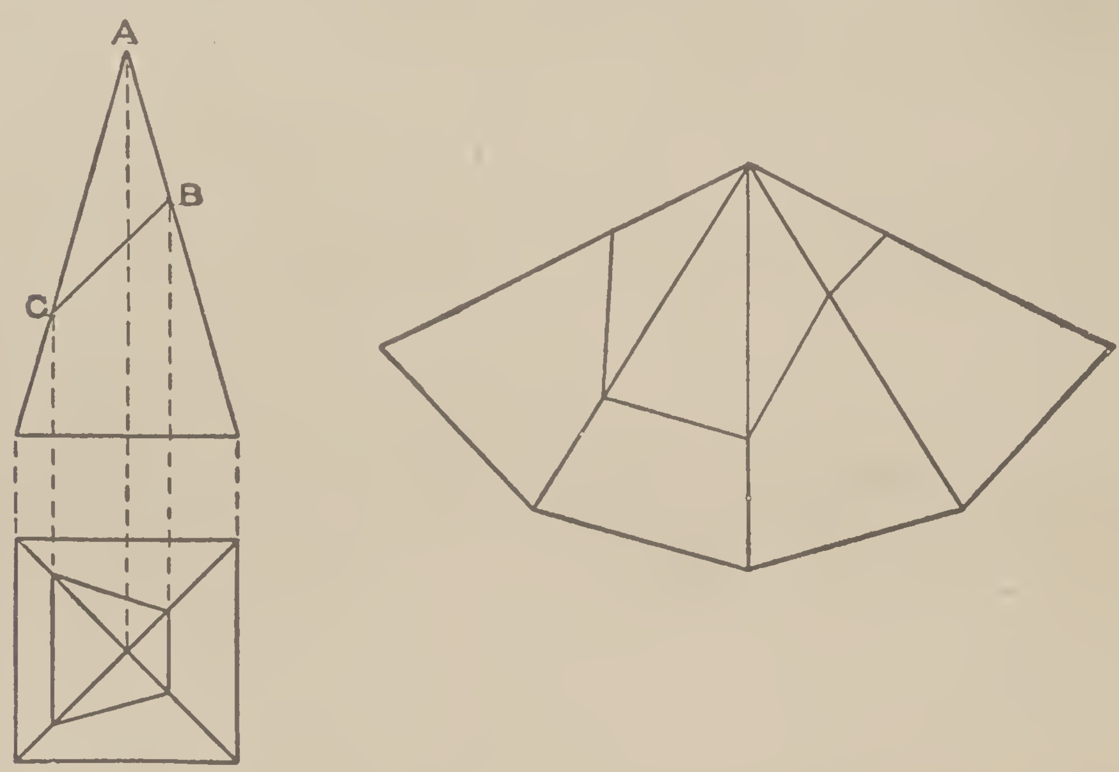


Fig. 97.

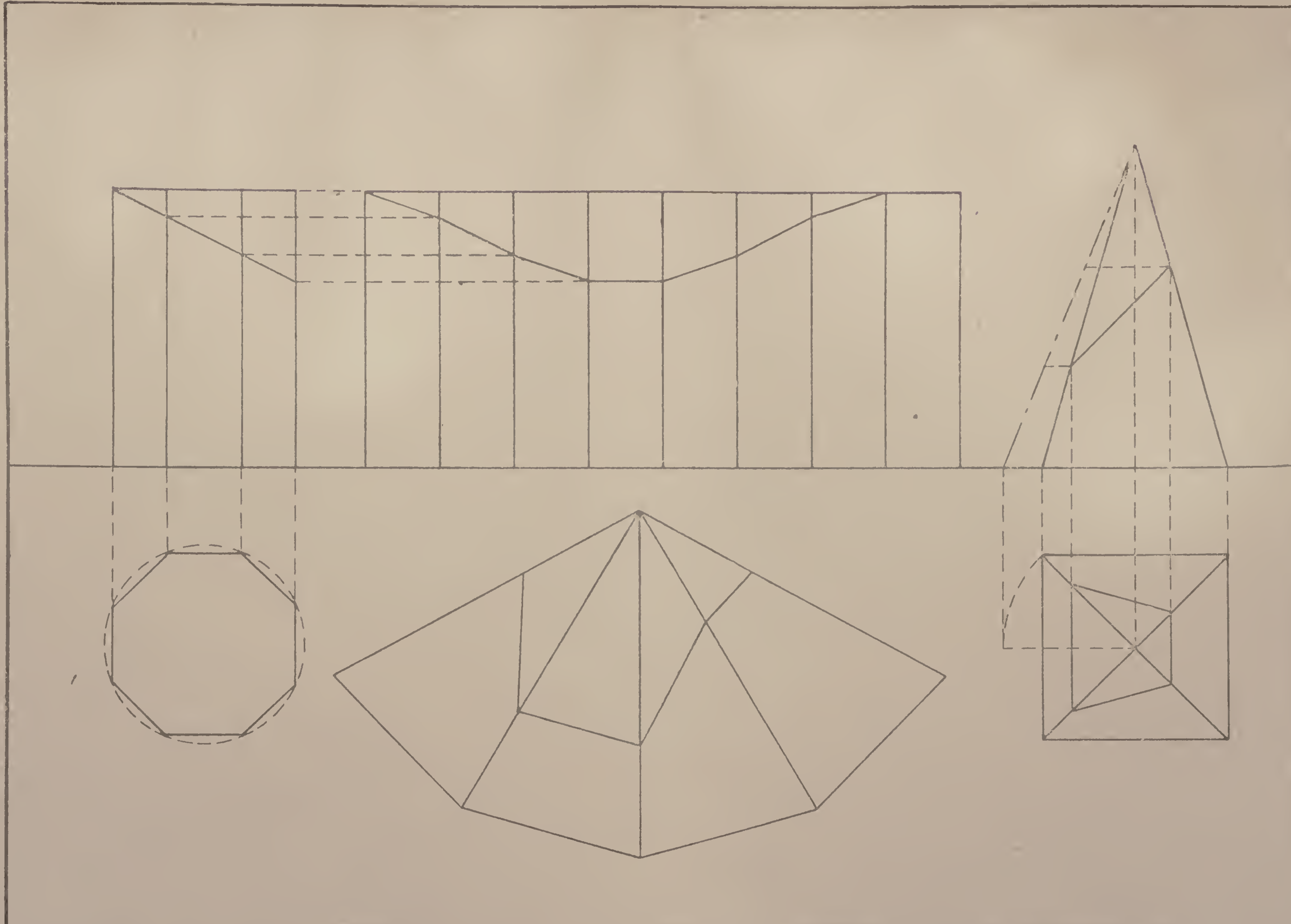
The plane forming the truncated pyramid is passed in such a position that A B equals $1\frac{3}{8}$ inches, and A C equals $2\frac{1}{2}$ inches. In this figure the development may be drawn in any convenient position, but in the case of the prism it is better to draw the development as shown. Indicate clearly the construction by inking the construction lines.

PLATE XIII.

Isometric and Oblique Projection.

Draw the oblique projection of a portable closet. The angle to be used is 45°. Make the height $3\frac{1}{2}$ inches, the depth $1\frac{1}{2}$ inches, and the width 3 inches. See Fig. 98. The width of the closet

PLATE XII



MARCH 7, 1907

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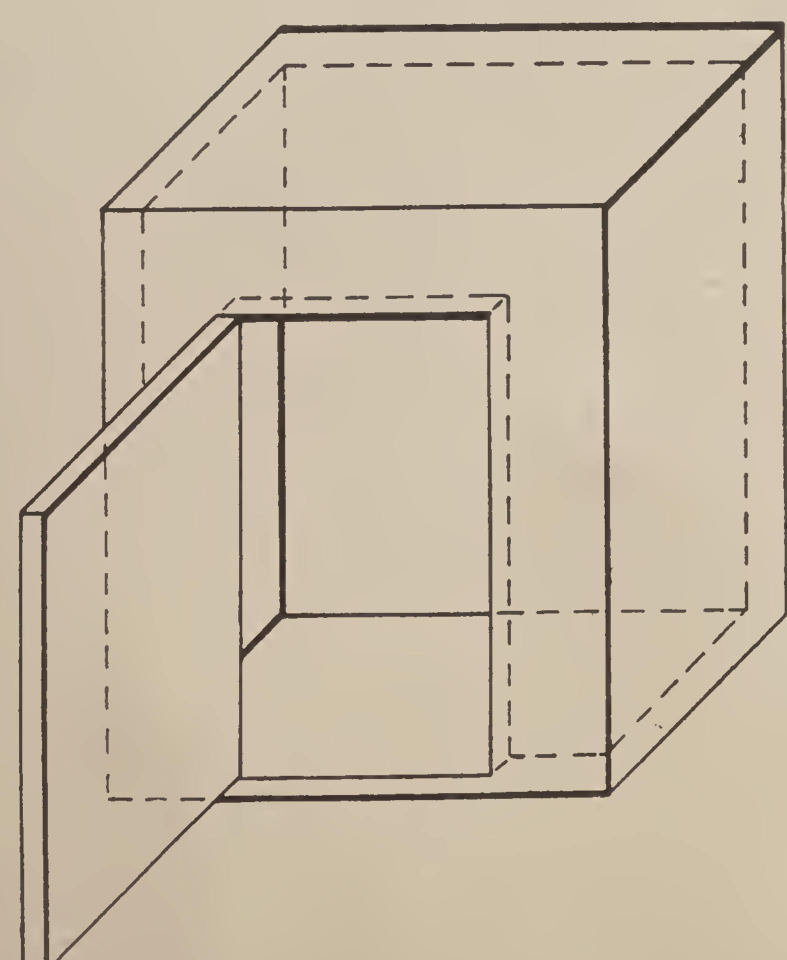
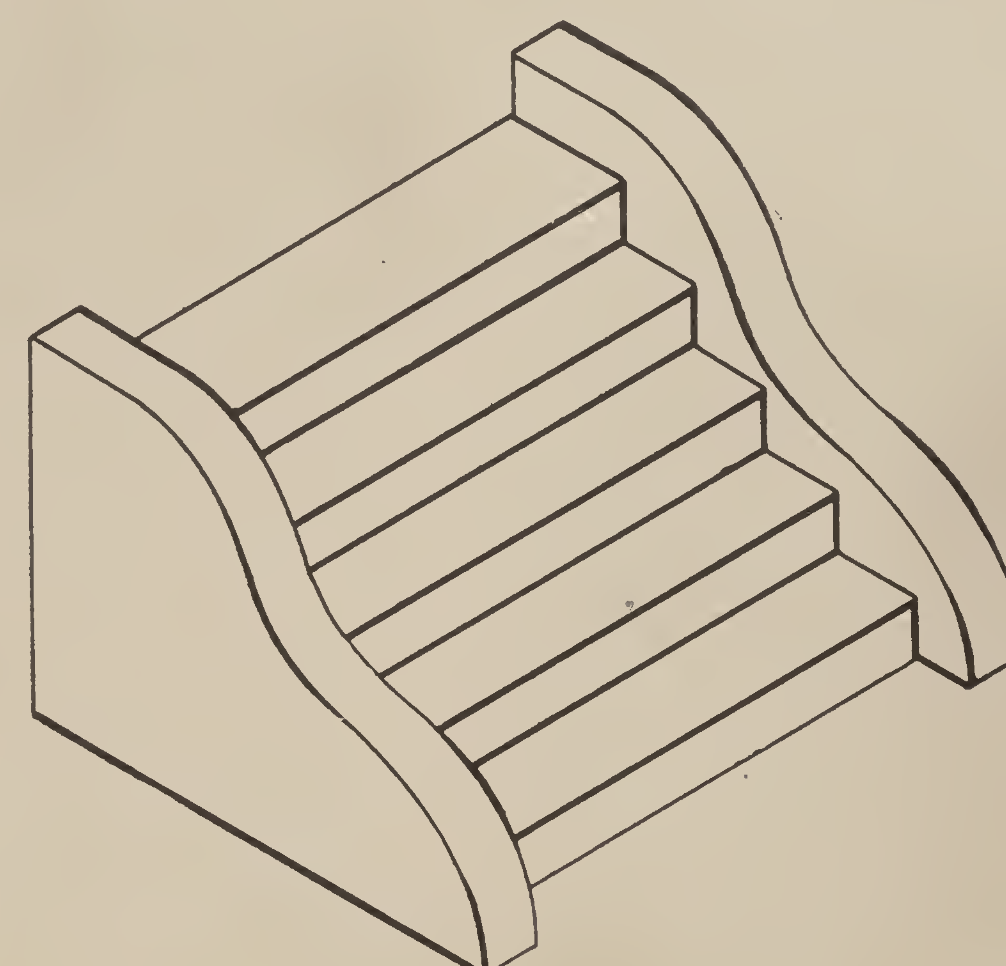
PLATE XIII





MARCH 14, 1907 HERBERT CHANDLER CHICAGO, ILL.

is to be shown as the left-hand face. The front left-hand lower corner is to be 1 inch from the left-hand border line and 2 inches from the lower border line. The door to be placed in the closet should be $1\frac{5}{8}$ inches wide and $2\frac{3}{4}$ inches high. Place the door

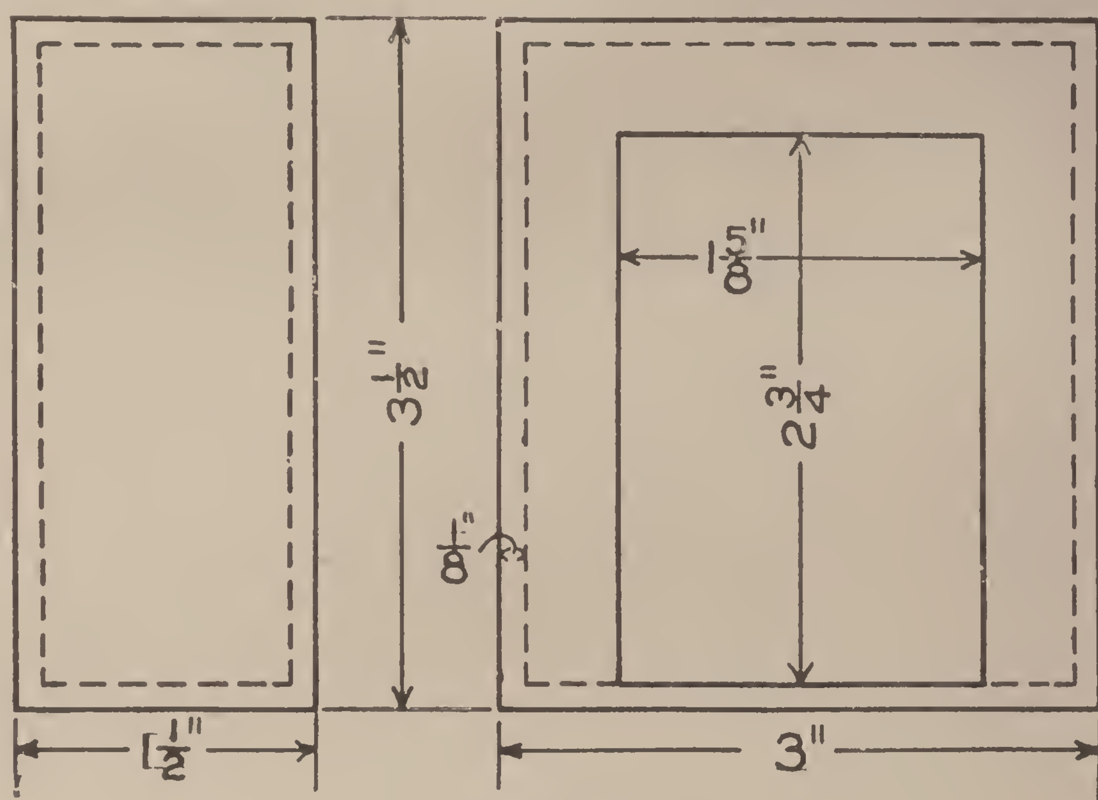


Fig. 98.

centrally in the front of the closet, the bottom edge at the height of the floor of the closet, the hinges of the door to be placed on the left-hand side. In the oblique drawing, show the door opened at an angle of 90 degrees. The thickness of the material of the closet, door, and floor is $\frac{1}{8}$ inch. The door should be hung so that when closed it will be flush with the front of the closet.

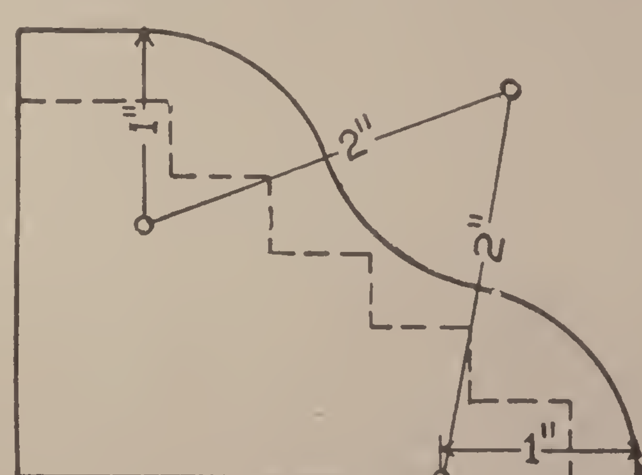


Fig. 99.

Make the isometric drawing of the flight of steps and end walls as shown by the end view in Fig. 99. The lower right-hand corner is to be located $2\frac{1}{4}$ inches from the lower, and 5 inches from the right-hand, margin. The base of the end wall is $3\frac{1}{8}$ inches long, and the height is $2\frac{1}{4}$ inches. Beginning from the back of the wall, the top is horizontal for $\frac{5}{8}$ inch, the remainder of the outline being composed of arcs of circles whose radii and centers are given

in the figure. The thickness of the end wall is $\frac{3}{8}$ inch, and both ends are alike. There are to be five steps; each rise is to be $\frac{3}{8}$ inch, and each tread $\frac{1}{2}$ inch, except that of the top step, which is $\frac{3}{4}$ inch. The first step is located $\frac{3}{8}$ inch back from the corner of the wall. The end view of the wall should be constructed on a separate sheet of paper, from the dimensions given, the points on the curve being located by horizontal co-ordinates from the vertical edge of the wall, and then these co-ordinates transferred to the isometric drawing. After the isometric of one curved edge has been made, the others can be readily found from this. The width of the steps inside the walls is 3 inches.

PLATE XIV.

Free-hand Lettering.

On account of the importance of free-hand lettering, the student should practice it at every opportunity. For additional practice, and to show the improvement made since completing Part I, lay out Plate XIV in the same manner as Plate I, and letter all four rectangles. Use the same letters and words as in the lower light-hand rectangle of Plate I.

PLATE XV.

Lettering.

First lay out Plate XV in the same manner as previous plates. After drawing the vertical center line, draw light pencil lines as guide lines for the letters. The height of each line of letters is shown on the reproduced plate. The distance between the letters should be $\frac{1}{2}$ inch in every case. The spacing of the letters is left to the student. He may facilitate his work by lettering the words on a separate piece of paper, and finding the center by measurement or by doubling the paper into two equal parts. The styles of letters shown on the reproduced plate should be used

PLATE XV

COURSE

IN

MECHANICAL DRAWING

AMERICAN SCHOOL

OF

CORRESPONDENCE

CHICAGO, ILL., U.S.A.

APRIL 24, 1907 HERBERT CHANDLER CHICAGO, ILL

INDEX